TRANSACTIONS

OF THE

ROYAL SOCIETY OF SOUTH AFRICA

VOLUME XXXV—PART II
1957

CAPE TOWN
PUBLISHED BY THE SOCIETY

1957

Issued July, 1957

Price 20s.

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OBITUARIES

EDWIN LEONARD GILL

Edwin Leonard Gill was born in England on November 17, 1877, of Quaker parentage. He graduated at Manchester University, where later he took a D.Sc. degree. He was appointed to the Manchester Museum, and from there to the Curatorship of the Hancock Museum at Newcastle-on-Tyne, which post he held for some twenty years. This museum is famous for its collection of fossil fishes, but Dr. Gill did little work on this subject as his main interest was birds. This led to his accepting a post in the Royal Scottish Museum, Edinburgh, where he was in charge of the Bird Department.

Two years later he was appointed Director of the South African Museum in succession to Dr. L. Péringuey. He arrived in Cape Town in December 1924 and entered upon his duties on January 1, 1925. By his energy and enthusiasm he brought about many improvements in the exhibition galleries in a comparatively short time. Two of his innovations may be quoted as of outstanding importance: the exhibition of local wild flowers, started in 1931 and still continuing, and the School Museum Service which was begun in 1935 and has since developed into one of the most important functions of the Museum from an educational point of view.

Dr. Gill's output of strictly scientific publications was small because his manifold interests, directly and indirectly connected with the Museum, left little time for original research. It is an unfortunate paradox that the Director of a Natural History Museum has to be a scientist, but has less time than any of his staff for research owing to the need for frequent interviews with members of the public, the press, and various learned societies, and to the duty of entertaining visiting scientists at their port of entry to the Union.

Dr. Gill was accompanied to the Cape by his sister, Miss Marion Gill, an accomplished artist, and together they soon established themselves in artistic circles and their social activities had no small effect in maintaining the prestige of the Museum. Birds continued to be Gill's main interest, but to the regret of his fellow ornithologists, he published very little out of his wide knowledge of the distribution and habits of South African birds. He was the first President of the reconstructed South African Ornithological Society in 1930, and President again in the Society's Jubilee year, 1954–5. His very popular *First Guide to South African Birds*, illustrated by Miss Marion Gill, was published in 1936 and is now in its fifth edition; he was revising it for a new edition at the time of his death. He died on July 5, 1956.

He was a member of the Royal Society of South Africa since 1925, and was elected to fellowship in 1929.

K. H. B.

DR. ERNEST JOHN HAMLIN

Dr. Ernest John Hamlin was born on March 17, 1887, and was educated at Merchant Venturer's School and the University of Bristol.

In 1911 he was appointed Lecturer in Civil Engineering at the University of Cape Town and left in 1913 to become town engineer at Stellenbosch where he remained for fourteen years.

During his period of office at Stellenbosch he designed and constructed the sewerage system for the town. It was also during this period that he obtained his doctorate at the University of Bristol. He was appointed Assistant City Engineer in Johannesburg, becoming City Engineer in 1932, a post which he held until 1947.

His work at Johannesburg was connected with the sewering of the outside districts and the establishment of treatment plants. He was responsible for the ultimate sand filtering of the effluent, thereby reducing the number of pathogenic organisms to a marked degree. He was a past member of Council of the Institution of Civil Engineers of London, President of the S.A. Institution of Civil Engineers in 1933, a Member of the Institution of Electrical Engineers and a Member of the Institution of Mechanical Engineers. He served for many years as a member of the Examining Board of the Royal Society of Health in South Africa and he was a Fellow of the Royal Society of Health.

After retiring from the City Council of Johannesburg he set up as a consultant and established a firm under his name. He continued to consult on various major engineering works up to the time of his death, on April 19, 1956. He was a member of the Royal Society of South Africa since 1913, and was elected to fellowship in 1922.

PRESIDENTIAL ADDRESS

THE GEOPHYSICIST AND SOME GEOLOGICAL PROBLEMS

By S. H. Haughton

In this short address I propose to touch upon one or two questions concerning the history of the earth which have, mainly within the last couple of decades or so, attracted the interest of the physicists and to whose elucidation several disciplines are now being integrated. For a long time, geology was considered in general as a natural science, one in which the observation of natural phenomena, their description, and the drawing of conclusions therefrom took pride of place over any severe mathematical treatment. Some of the aspects of earth history were, of course, studied in that time by people who were not primarily field geologists; these questions included those dealing with the age of the earth, the nature of its core below the visible crust, its mode of origin, and its cosmic significance; but the average working geologist, frequently under the necessity of showing that his studies had a 'practical' value, tended to consider that such matters were not those in which he could be expected to take a lively interest. I well remember that when A. L. du Toit first began to talk about the hypothesis of continental drift, one of his colleagues expressed his regret that du Toit should have forsaken the straight path of geological observation for the devious ways of unjustified speculation.

It must be recognized, however, that to-day such an expression of regret would be unfashionable. Observations are still the backbone of the science of geology; but to those made by the eye in the field or in the petrological, mineralogical, and palaeontological laboratories we now add the observations made by the varied types of instrument that the physicist has placed at our disposal. Not only to the 'practical' geologist in his search for mineral deposits, including water supplies, below the zone of outcrops have the studies of the geophysicist proved of considerable value, but they are playing their part in the struggle to elucidate fundamental problems of earth history. Instances of this will appear in the sequel.

The Study of the Precambrian

The rocks that have been assigned to the Precambrian were formed during a period of time that extended for approximately the first five-sixths of the history of the earth's crust. The elucidation of their inter-relationships is rendered more difficult than is that of the various later systems and series in the stratigraphical sequence by the absence of specifically recognizable fossil remains of animals or plants and by the many vicissitudes which they have undergone during their prolonged history. These

have caused changes of varying degrees in their mineral content and structure, adjustments and alterations in their attitudes, and disruptions in their areal continuity. Acting as a basement on which were deposited the fossil-bearing sediments which comprise the geological column from early Cambrian times to the present day, they are in many places now hidden from sight. Field continuity is thus interrupted from area to area, so that correlation problems have to be considered as problems of assessment rather than of direct observation in the majority of cases.

The question of correlation is something more than an academic exercise. Many of the more important mineral deposits in Africa are to be found in rocks that are Precambrian in age, and evidence is accumulating to the effect that a specific mineral or a specific group of allied minerals may have been concentrated at a single period during the long Precambrian history. Consequently, the location in time of a rock or a group of rocks may be a clue to the potential discovery of a particular type of mineral deposit. The Precambrian rocks of Africa south of the Sahara consist of argillaceous, arenaceous, and calcareous sediments, effusive igneous rocks, and intrusive magmatics. In most cases their original nature has been altered by various metamorphic agencies, thermal and dynamic, which have varied in intensity from place to place. The degree of intensity of metamorphism is not, however, solely a function of age; and it is not possible to assume a greater antiquity for rocks that are highly metamorphosed than for those less highly metamorphosed, even in a single region, on that basis alone; nor is it unlikely that rocks of the same age in two separate regions may show different degrees of metamorphism. A striking example of this is provided by the sediments of the Lomagundi system in Southern Rhodesia which, as they are followed along their northerly strike from their southern extremity in the direction of the Zambezi valley, show increasing degrees of metamorphism. A further example is provided by the rocks of the Kheis system in the Union of South Africa which become increasingly altered as they are traced from their more southerly outcrops in the Kenhardt district northwards and north-westwards to the Orange river area of Gordonia and South-West Africa. Although here the rocks consist predominantly of gneisses and schists they continue to display the tectonic features of a series of folded sediments—domes and basins, anticlines and synclines, and faults—which are beautifully shown in the air photographs of this barren region, and which have been carefully mapped by officers of the Geological Survey.

Within any single area of continuous outcrops, the principle of true superposition can often be used to determine the relative antiquities of two or more series of unfossiliferous rocks; but the principle is of no value in attempting correlations between the rocks of widely separated areas. Detailed mapping, for example, has elucidated the sedimentary successions in the Precambrian rocks of both the Barberton and Richtersveld areas of the Union of South Africa; but synchroneity or otherwise of the rocks within the two successions cannot be proved by direct field mapping nor by lithological comparisons.

Weight has been given by various writers to the value, for correlation purposes, of evidence for regional glaciation afforded by certain Precambrian rocks in Africa. Deposits laid down terrestrially or subaqueously as the result of transport by ice are

considered to have specific characteristics and are known as 'tillites'; and the presence of seasonally banded sediments in the form of varved deposits is additional evidence of the existence of glacial conditions prevalent at the time of their deposition. Rocks designated as tillites, with or without accompanying varves, have been recorded from various parts of Africa as occurring in the Precambrian succession at more than one stage. In so far as any of these can be shown to be of regional importance and definitely to be of glacial origin, it is possible to utilize them in correlation over more than local areas. The well-known example of the late Palaeozoic glaciation evidenced by the widespread tillites of South America, South Africa, Madagascar, India, and Australia may be cited as an example of the utilization of such phenomena in making broad time correlations over large distances. Even in this case, however, doubt has been thrown upon the exact synchroneity of the tillites found in the various continental masses.

Yet another approach to the problem of correlation of unfossiliferous rocks is based on tectonics of folded belts. Contemporaneity of orogenic movements and the similarity of direction of fold axes which may result therefrom do not, however, necessarily imply contemporaneity of deposition of all the rocks that are involved in such movements.

Of recent years, considerable attention has been given to the determination of the absolute or apparent ages of certain minerals by the methods of isotope analysis. The methods are based on the rate of decay of certain elements and on the ratios of the original elements and their decay products present in a mineral.

The *isotopic lead-uranium method* of age determination is considered to form the primary calibration for the geologic time-scale. Most uranium- or thorium-bearing minerals contain three long-lived radioactive isotopes, U^{238}, U^{235}, and Th^{232}, which decay at different rates and possess unique decay chains involving several elements. The final products of decay of these three isotopes are Pb^{206}, Pb^{207} and Pb^{208}. If it be assumed that nothing is added or removed during the process of decay from parent element to daughter element and if the rate of decay be known and is constant, it is possible by measurement of the relative amounts of parent and daughter elements present to determine the time which must have elapsed since decay of the parent first began.

The simplicity of this approach, however, is in practice embarrassed by a number of complicating factors. In the first place, some uranium minerals carry what is known as *common lead*, i.e. lead which is not the product of the decay of one of the radioactive elements but is an original constituent of the mineral. This common lead (or *original lead* in Holmes's terminology) is composed of four isotopes—Pb^{204}, Pb^{206}, Pb^{207}, Pb^{208}. Consequently, it becomes necessary to correct the quantities of Pb^{206} and Pb^{207} found in a non-thorium-bearing uranium mineral by measuring the quantities of Pb^{204} and Pb^{208} present and estimating how much of the Pb^{206} and Pb^{207} found is due to the presence of original lead. To do this, it is necessary to determine, as accurately as possible, the isotopic composition of the particular original lead that was present and included when the uranium mineral was formed. This is a matter of no small difficulty, and geological evidence for the association of a

particular original lead with the uranium mineral under examination is essential. Both should have formed from the same solution. It has, however, been stated that the error introduced by the variability of common lead will not be serious if most of the lead present is radiogenic.

Other potential sources of error lie in the possible differential losses of material during the life history of the sample whose age is being determined by this method. One of the stages in the decay of U^{238} is the formation of the gas radon^{222}, which has a half-life of 3·82 days and which may diffuse away from the system. Whether or not such a loss is significant under natural conditions is still a matter of investigation; but any loss of radon would result in a low value for Pb^{206} and in an apparent age lower than the true age. On the other hand, hexavalent uranium is much more readily leached than lead and, therefore, should the mineral have been subjected to leaching processes throughout its life, the uranium value will be lowered and the apparent age will be greater than the true age. Involving as it does mass-spectrometric analysis of lead, the method depends for accuracy upon a minimum of experimental errors.

The method results in the acquisition of figures for the ratios:

radiogenic Pb^{206}/U^{238}
radiogenic Pb^{207}/U^{235}

and, if thorium be present, for the ratio

radiogenic Pb^{208}/Th^{232}

Knowing the ratio of the three parent isotopes and the half-life of each, each of these ratios can be converted into an age in years, during which decay has proceeded. For a single mineral from a particular geological setting, the three ages so obtained should agree with each other; they seldom do. Eckelmann and Kulp (*Bull. geol. Soc. Amer.*, lxvii (1956), p. 35) state, 'In only about 30% (of several dozen determinations) did the ages derived from the three isotopic ratios (i.e. Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206}) agree within the experimental error'. Ages derived from the Pb^{208}/Th^{232} ratio almost always disagree with the others.

A consequent method of age calculation, using corrected values for radiogenic lead isotopes, uranium and lead analyses, and the decay constants, is by solving the equation

$$\frac{\text{Radiogenic } Pb^{207}}{\text{Radiogenic } Pb^{206}} = \frac{U^{235}(e^{\lambda_1 t} - 1)}{U^{238}(e^{\lambda_2 t} - 1)}$$

where the chemical symbols indicate the number of atoms of each isotope, λ_1 and λ_2 are the decay constants for U^{235} and U^{238} respectively, and t is the age. The ratio $U^{235}: U^{238}$ is 1 : 138. This is known as the *lead: lead method*; it deals only in isotopic ratios, but it also is subject to errors arising from loss of radon, uncertainty in the composition of the original lead, and the presence of old radiogenic lead formed in a prior site of the parent uranium.

Considerable interest has been displayed during the past few years in the study of zircons by the *lead-alpha* method. Larsen and his co-workers found that zircon and some other fairly common minerals (xenotime, monazite) are comparatively resistant to chemical change and were sufficiently low in original lead at the time of their

formation to satisfy the requirements necessary for a fairly satisfactory age determination. The method consists of establishing the lead content of the mineral by spectrochemical analysis and the uranium (or thorium) content by thick-source alpha activity. If both uranium and thorium are present, it is necessary to obtain the uranium content by a fluorimetric analysis.

Methods of age estimation, based on other parent-daughter relationships, have come into prominence during the past few years. One of these is known as the *strontium-rubidium method* and is based on the beta decay of Rb^{87} to Sr^{87}. Certain potassium-bearing minerals, such as lepidolite in particular, biotite, muscovite, amazonite, pollucite, and caesium beryl, tend to show a high enrichment in rubidium and are thus especially suitable for study by this method. On the other hand, strontium tends to be associated with calcium; consequently the minerals with high rubidium concentration are likely to contain negligible amounts of original, non-radiogenic strontium.

A second is the *potassium-argon method*. Potassium, which is widespread in nature, has three naturally occurring isotopes, K^{39}, K^{40}, and K^{41}. Of these, K^{40} is by far the least abundant; it is, however, radioactive, and decays, by K-electron capture, to argon (A^{40}) with gamma emission and to calcium (Ca^{40}) with beta emission. The K^{40} isotope is long-lived; but its decay constants are as yet somewhat uncertain. Both of these methods are considered to be of greater potential applicability than any of the various lead-uranium methods because of the restricted nature of the occurrence of uranium minerals.

Several hundred age determinations have been made by various investigators on Precambrian minerals from Africa. Consideration of the methods employed, however, make it clear that the determinations are not all of the same rank of accuracy; and it is necessary, at the present stage of knowledge, to distinguish between them and to classify them into what have been called (*a*) absolute, (*b*) apparent, and (*c*) conventional ages. These ages are, of course, applicable to the actual minerals that have been examined and hence to periods of mineralization. The relationship between the age of a particular mineral and the age of the rocks which form its environment must, of course, be determined on geological grounds. Epigenetic mineralization is younger in age than the rocks in which it has been induced; but if a mineral is remanié in the rock in which it occurs, or if it has suffered subsequent re-working by solution and re-deposition, or by other means, the age attributed to it by isotopic analysis cannot bear any calculable mathematical relationship to that of the rock in which it is enclosed.

It is clear that, in assessing the value of the results obtained in the laboratory by the chemist and physicist working on a particular mineral sample, it is essential for the geologist to elucidate the past history of the sample as far as it is possible for him to do so and to learn its true relations to the rock from which it was obtained. Without a sufficiency of data, age determinations may be susceptible to more than one interpretation. Two examples may be given to illustrate this point.

The pitchblende of Shinkolobwe in the Katanga has been the subject of numerous rigorous analyses and there is general agreement that its age is approximately 635

million years. It occurs in mesothermal veins in dolomitic rocks attributed to the *série des Mines* of the Roan system, whose age therefore must be greater than that of the pitchblende. There are, however, certain Cu-Pb-Zn veins (such as Kipushi) which cut Kundelungu deposits and whose injection is considered to be bound up with the Kundelunguian orogeny. Galena from these veins, studied by chemical analysis, has given an apparent age of about 600 million years, and certain geologists have therefore considered that the Kundelungu system must be older than this and thus belong to the Precambrian. Robert, however, believes the Kundelungu to be Palaeozoic and explains the evidence afforded by the galenas by supposing that, although the galena was formed at the same time as the Shinkolobwe pitchblende, it was caught up in the Kundelungu intrusion and became part of the Kipushi vein without alteration of its isotopic constitution.

The second example concerns the age of the Witwatersrand system of rocks in South Africa. Certain auriferous conglomerates in this system are comparatively rich in uraninite. Samples of this uraninite have been subjected, both in South Africa and overseas, to complete uranium-lead analysis and age determinations made from the figures obtained thereby. Little attention seems to have been paid by some of the analysts to the exact geological setting of the samples analysed, and some anomalous results have been obtained, leading to the conclusion that more than one generation of uraninite is present within the system. Nevertheless, there is general agreement that some of the uraninite studied is as old as 1900 M.Y. To those geologists, mostly overseas, who believe in an epigenetic origin of the uraninite in these sediments, this means that the figure given is the minimum age for the Witwatersrand system and that the system may be older. To those, however, who consider that at least part of the uraninite was deposited at the same time as the sediments in detrital form (and for this belief there is evidence derived from a petrographic study of the sediments themselves) this age of 1900 M.Y. is the age of the rocks from which the uraninite was eroded and transported and is thus a maximum age for the system, which may be considerably younger.

These two examples are given merely to assist in stressing the necessity for prudence in utilizing age determinations for correlating Precambrian rocks between regions, even assuming that the laboratory figures can be accepted without reserve.

Submarine Geology

The promulgation of ideas relating to the permanence or impermanence of ocean basins and of continental masses has long been a feature of geological study. During the past three decades much energy has been expended in arguments concerning the validity of the hypothesis of continental drift, first suggested by Taylor, propounded at length by Wegener, and vigorously supported by, among others, A. L. du Toit. Compared, however, with the detailed knowledge we possess of the structure and composition of the continental masses, that which was available regarding the ocean floors was meagre, even in so far as the physical geography was concerned.

There is now, however, an intensification of interest in the study of the rocks below the oceans—submarine geology—by such means as are available. These

include dredging and coring for the recovery of actual rock material, echo-sounding for the charting of the submarine surface, geophysical surveys by magnetometric, gravimetric, and seismic-refraction methods, and the study and measurement of earthquake surface waves. Marine geology is to-day possibly the fastest expanding field of geology.

It is not possible here to describe in detail the results of recent investigations. In general terms it would appear, however, that apart from anomalous regions such as the continental margins along which rapid sedimentation is proceeding, mountain ranges, deep-sea troughs, and island arcs, crustal structure is remarkably uniform both within continents and within ocean basins. The structures, however, differ in that, whereas the continental crust can be considered to have an average composition of a silicic layer 35 km. thick underlain by a mantle of ultramafic rock, the crustal structure of oceanic area shows this M discontinuity at a depth of 10–11 km. beneath the sea surface, overlain by a mafic layer about $4\frac{1}{2}$ Km. thick covered with a thin layer of consolidated sediments or volcanics. Such a difference agrees with the implications that arise from the theory of isostasy; but a continuation of the observations that are being made and an intensification of study of the critical marginal areas are necessary in order that a more accurate picture may be obtained.

For a number of decades it has been stated that there is a broad petrographic contrast between the sialic rocks of continents and the olivine basaltic and other mafic and ultramafic rocks of ocean basins. Gilluly (1955) has pointed out that the records of the oceanic occurrences of rocks more siliceous than basalt show that this broadly valid generalization has tended, by repetition, to be considered absolute, and that the difference in petrological composition between oceanic and continental crustal segments is merely statistical and not exclusive. He suggests that investigation of such rises as the Walfisch ridge may show them to be composed of rocks of intermediate mean density. Nevertheless, the bulk of the evidence at present available shows that the 35 per cent of the globe's surface formed by the continents and the continental shelves are fundamentally sialic and sedimentary in origin (including the metamorphosed and metasomatised Precambrian rocks) while the ocean basins are not. The evidence within the continents of repeated cycles of accumulation, deep burial, metamorphism, uplift and erosion has not so far been found in the rocks flooring the ocean basins; and the full explanation of this difference is yet to be found.

Nevertheless, it is clear that the ocean floor has, at least in parts, not been static throughout geologic time. Hamilton, in a recent publication (*Mem. geol. Soc. America*, lxiv, 1956) has given an interesting account of studies made in the mid-Pacific ocean. Between Hawaii and Wake Island there is a range of submarine mountains in which occur a number of flat-topped peaks or seamounts, called guyots by Hess. These flat-topped guyots are to-day submerged to depths of between 700 and 900 fathoms. Some of them were surveyed by echo-sounding, dredging, and coring. Their history would seem to be as follows. During the Cretaceous the guyots were a chain of basaltic islands rising from a submarine ridge. These islands were wave-eroded to flat banks on which grew corals and rudistids with gasteropods and lamellibranches which had affinities with the Aptian to Cenomanian fauna of the Tethyan province of the

Caribbean. Subsidence which carried the tops to below the zone of coral growth took place during the Upper Cretaceous. Paleocene and Eocene foraminifera were deposited on the tops of some of the guyots. Subsequently, subsidence of the mountain range took place to the present depth. It is of interest to the student of palaeontology to note that Hamilton considers the presence of these Cretaceous islands in the mid-Pacific as possibly assisting in the distribution of certain kinds of marine fauna—the islands acting as 'stepping-stones' which could have been used by the larval forms of animals whose adults could only flourish in a coastal shallow-water environment.

The mid-Atlantic ridge, which stands some 2–3 km. above the sea floor with a length of some 10,000 km. and an average width of some 500 km., has been considered by some geologists to be a folded mountain system with consequent thickening of the crust above the M discontinuity, while others believed it to be a thick section of volcanic material lying on a normal oceanic crust or intruded into it. Hess has suggested that it may be the result of a 'welt' of serpentinization formed below the M discontinuity by water rising from the mantle reacting with olivine. The formation of serpentine in this way would result in a considerable volume increase and a consequent rise in the surface of the sea floor.

Many individuals and organizations are now working on marine geology, integrating all the sciences bearing upon the problems of crustal formation and deformation; and it is not too much to expect that the next decade will see notable advances made in the accumulation of observed facts and in the synthesis of a theory based upon those facts. It is to be hoped that more work will be done in the South Atlantic areas that are of particular interest to South Africans.

Palaeomagnetism

Another conjoint field of enquiry is that of palaeomagnetism. Lava flows and other igneous rocks become magnetized in the direction of the local field when they cool down after their formation. Similarly, some sediments acquire a weak magnetic polarization on deposition. Studies of certain rocks show that they are magnetized in a direction which is quite different from that of the earth's present field. It is postulated that in at least some of the cases the direction is that of the earth's field at the time when the rocks were formed. Assuming this postulate to be true, it should be possible, by measuring the direction of the field in rocks of the same age at various points of the earth's crust, to compare the position of the magnetic poles at the time of the formation of those rocks with the present polar positions. Should the measurements of rocks of a single age point to a single location for one of the poles, and should that location not be that of the present pole, there would be presumptive argument in favour of magnetic polar wandering. Should, on the other hand, rocks of the same age in two different continents point to two differing locations for one pole, it is considered by some that this would constitute an argument in favour of continental wandering.

There are a number of questions relating to the magnetization of both igneous and sedimentary rocks which are not properly understood as yet. Nevertheless, it is

possible that, given sufficient measurements, these will provide answer to the question of which measurements may be considered reliable palaeomagnetic data and which are unreliable.

A large amount of effort is going into the prosecution of studies in this field. Measurements on South African material are being made by Professor Hales and his co-workers at the Bernard Price Institute for Geophysical Research at Johannesburg; these are, however, but a small part of the almost world-wide studies now in progress. A recent conference in London on palaeomagnetism held under auspices of the International Union of Pure and Applied Physics was attended by more than fifty delegates from Britain, United States, Japan, France, Holland, Germany, Iceland, and South Africa, who reviewed the information available from these countries. In Britain, the Department of Scientific and Industrial Research is financially supporting studies by teams of workers at three university centres—Newcastle, London, and Cambridge. Work is also being undertaken in Australia and in India, in addition to the countries represented at the Conference. Conclusions reached by the physicists in this field are assured of critical scrutiny both by the workers themselves and by geologists.

Seismology

The value of the study of seismic waves in an interpretation of crustal structure and of the earth's internal composition has long been recognized. By its means, the M discontinuity between a 'crust' and a 'core' has been found in many areas as a physical discontinuity; but Birch has recently expressed his personal uncertainty regarding the extent to which this is also a chemical discontinuity. Certain of the older ideas regarding crustal structure derived from seismic observations are undergoing revision. As Birch has said, 'The recent seismological work by Tuve and Tatel, Gane, Willmore, and others, has left the concept of crustal layering in a weak, probably a dying, condition. A more realistic view, in closer conformity with visible basement structure, is of a mosaic of intrusions of different kinds, metamorphosed sediments and volcanics, even—to depths of 10 km. or more in places—of unmetamorphosed sediments, all of this faulted and broken into blocks of various shapes and sizes.' He suggested that one reason for the apparent uniformity of the seismic velocities in so heterogeneous a crust may well be the relatively narrow range of variation for a fairly wide range of composition.

It would seem that much work remains to be done on the physical nature of the metamorphic rocks that, in Africa particularly, form so large a part of the crust. Correlation of wave velocity and composition in these is not at present possible as it is for igneous rocks; but the attribution of an observed velocity to 'granite' could easily be erroneous, since quartzite has velocities not very different from that of granite in the same way as those of dolomite are close to those of gabbro (Birch). The effects of temperature and pressure on velocities have as yet been studied for but a comparatively few rocks; experimental investigations on silicate rocks ought to be considerably extended.

Some African Problems

It is of interest to look briefly at some of the fundamental problems offered by a study of the present-day structure of Africa south of the Sahara and to consider the assistance which further geophysical attacks could give to their solution. As has been indicated, age determinations and palaeomagnetic measurements on continental rocks are the subject of some intensive studies; but what of the history of the areas contiguous to the continent?

The nature of the visible portion of the 'Cape Folded Belt' and of the rocks involved in it has been the subject of many geological studies. We know that a thick succession of sediments ranging in time from at least the base of the Cape system through Bokkeveld, Witteberg, Dwyka and Ecca times has, along the southernmost belt of the continent, been thrown into folds with approximately east-west axes and with a tendency to overfolding in a northerly direction. Along the northern flank of the fold ranges the intensity of folding diminishes. Of the thick sequence of strata affected by this folding, only a maximum of 2,000 feet in the lower three-fifths of the Bokkeveld beds contains evidence of marine deposition. Close study of the lithology and dimensions of the beds of the Ecca series within and to the north of the folded ranges points to a southern source of origin; and it appears probable that the thick mass of Dwyka tillite in this southern belt was also mainly derived from a southern land mass. Through Beaufort times the folded mountains suffered denudation. The wedge-shaped mass of Molteno beds with its conglomerates and predominant sandstones must have derived its material from a southerly direction; and denudation in Karroo times was sufficiently intense for the Stormberg sediments and lavas in the Springbokvlakte area north of Uitenhage to be deposited unconformably upon folded Bokkeveld beds. At the earlier end of the time-scale, rocks of pre-Cape age are to-day exposed in the worn-down cores of the anticlinal folds.

Towards the east, the east-west strike of the fold axes bends to a certain degree towards the south; but the folds are truncated abruptly by the present coast-line at their visible eastern end. Where, then, is the southern sialic land mass from which the more southerly Karroo beds were derived, and where is the easterly continuation of the folded belt beyond the present coast-line? A series of gravitational and seismic observations and one of corings at sea off the stretch between Port Elizabeth and Port Shepstone would certainly increase our knowledge of the submarine geology of a very interesting area and throw light on the cause or causes of the general configuration of the existing coast.

Submarine studies, too, would assist in an understanding of the nature of the Mozambique channel, which seems to have constituted a sea-way between the African mainland and Madagascar since upper Permian times. Dixey has drawn attention recently to the nature of the two sides of this seeming geosyncline which, to him, has 'the character both of a subsiding basin and of a major rift feature, showing intermittent movement over a great space of time'.

A third area that is of very great interest is that lying within the present Gulf of Guinea. In the Gold Coast and adjacent territories much of the land mass consists

of a long succession of Precambrian rocks with an existing strike that runs approximately north-south. These appear to have been for the most part deposited in a meridional geosyncline bordered by land masses to the east and to the west and to have been invaded by granitic magma. Possibly in the Devonian, and certainly in the Mesozoic a new geosyncline appears to have superimposed; in this was laid down a thick series of Cretaceous and early Tertiary sediments, portions of which still fringe parts of the existing coast but which ought mainly to lie beneath the sea. This later geosyncline must have had its axis roughly parallel to the existing coast between Sierra Leone and the submarine Walfisch ridge. At the bend, where the axial direction changes from latitudinal to longitudinal, the feature is cut by the fractures on which lie the volcanoes of the Cameroons range, Fernando Po, Principé and Sao Thomé, of which the last three form islands rising from the floor of what may be a trough fault. Off-shore from the coast the continental shelf is comparatively narrow and the continental slope steep. What constitutes this steep slope and what is the nature of the ocean floor at its foot are at present matters of conjecture; geologists concerned with the study of the contiguous land would find of the greatest interest a knowledge that could put an end to this conjecture and replace it with a series of facts. For this reason, we welcome the initiative of Dr. Maurice Ewing of the Lamont Geological Observatory of Columbia University, who has decided to make observations in at least portions of the equatorial belt of the eastern part of the Atlantic Ocean as part of the researches undertaken by the Observatory's vessel *Vema*.

The solution of these and other fundamental geological problems posed by the African continent and the adjacent oceans demands an integrated attack by various disciplines, and in this attack scientists of Africa should play their part. By the very nature of the problems, the attempts at solution must be long-term in their conception and money-consuming in their progress. They cannot be expected to produce immediate material results. They involve the gradual accumulation of numbers of indisputable facts—geological, physical, and chemical—which are capable of correct interpretation.

Some efforts in this direction are being made by scientists in the Union and the neighbouring countries. Their results in the fields of age determinations, seismic studies, crustal heat, conductivity of rocks, and palaeomagnetism, are important contributions to our knowledge; but the fields are even wider than these, the workers are few, and the financial backing for larger-scale studies has not been forthcoming. The generous grant recently made by a South African to an English university for fundamental geological research on the African continent itself may inspire in us a hope that at some future date one at least of our own universities will be enabled to play a part in the attack upon some of the problems I have outlined, of which those relating to submarine geology are by no means the least fascinating.

SOME SOUTH AFRICAN BRYOZOA

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(Communicated by J. H. Day)

(Read May 16, 1956)

Part of the material described was obtained from the hulls of ships and from immersed experimental plates in Table Bay Harbour; the rest was collected during ecological work on the South African coasts. In all 36 species have been recognized. Of these one, *Parasmittina natalense*, is considered a new species and three, *Acanthodesia savarti*, *Conopeum reticulum* and *Cryptosula pallasiana*, do not appear to have been recorded previously from South Africa.

The well-preserved specimens in the present collection have allowed observations to be made on the wide range of variation in some species, on a new method of branching and on the ancestrulae and early development of certain species. It has also been possible to reconsider some of the previous identifications and to make certain necessary alterations in nomenclature.

I owe the opportunity of examining this collection to the kindness of Dr. N. A. H. Millard and desire to express to her my thanks. It was sent to me some years ago but various circumstances have prevented its examination before now. I wish to thank Dr. A. B. Hastings for her kind advice.

The Society desires to acknowledge a receipt of a grant from the South African Council for Scientific and Industrial Research towards the cost of publication of this paper.

PHYLUM ENTOPROCTA Nitsche, 1869

A common practice and one followed in previous contributions on South African Bryozoa has been to regard the Entoprocta as a sub-phylum or sub-class of the Bryozoa. Now, the fundamental differences between the two groups are more fully recognized and they are regarded as two phyla of equal rank. This was first proposed as far back as 1888 by Hatschek who retained Nitsche's name Entoprocta but his suggestion was not generally adopted. Clark in 1921 reopened the question by proposing that they should constitute a phylum Calyssozoa and Cori in 1929 altered the name to Kamptozoa. Here it is proposed to follow Hyman (1951) who regards them as an independent phylum but retains Nitsche's name as used by Hatschek, pointing out that as the name is a good one there is no need for change. Most workers on Bryozoa have treated them together and so for convenience (superficially they resemble the Bryozoa more closely than any other group and

they are collected together) they are both included in the present report while acknowledging the correctness of regarding them as separate phyla.

Family PEDICELLINIDAE

1. *Barentsia gracilis* (M. Sars)

Pedicellina gracilis M. Sars, 1835, 6.

This seems to be the same species as that previously recorded under the name *B. discreta* (O'Donoghue, 1924, 21) from off Cape Infanta in 30–40 fms. encrusting a hydroid. The present specimens were upon *Menipea crispa* from a mile off-shore between Blaauwberg and Milnerton, Table Bay, in 5–10 fms., and upon *Bugula calathus* from the hull of the *Pretoria*, Cape Town. Upon further examination this material seems to agree more closely with the descriptions of *B. gracilis* than of *B. discreta*. The length of an individual is about 1 mm. It is widely distributed and fully treated with synonymy by Harmer (1915, 29).

PHYLUM BRYOZOA

ORDER GYMNOLAEMATA
SUB-ORDER CHEILOSTOMATA

SECTION ANASCA

1. *Aetea anguina* (Linné)

Sertularia anguina Linné, 1758, 816.

Previously recorded from South Africa by Hincks, Hasenbank and O'Donoghue and de Watteville (q.v. for details 1944, 409). Present material from Kalk Bay, intertidal.

This consists of two small colonies, one growing over *Beania vanhöffeni*, which in its turn is growing upon *Menipea triseriata*; the other growing upon *Onchoporella buski*.

2. *Scruparia ambigua* (d'Orbigny)

Eucratea ambigua d'Orbigny, 1841, pl. iii, figs. 13-17; 1847, 11

Previously recorded from South Africa by O'Donoghue and de Watteville (1944, 410) as *Eucratea chelata*. Marcus (1940, 108) also states that *S. chelata* occurs there but gives no authority or details. Present material from a mile off-shore between Blaauwberg and Milnerton in 5–10 fms.; from Table Bay in 15½ metres and from Kalk Bay, intertidal, all upon *Menipea crispa* or *M. triseriata*.

The species often called *Eucratea chelata* is the *Sertularia chelata* Linné (1758) which Lamouroux (1816, 149o) referred to his genus *Eucratea* but, as pointed out by Harmer

(1923, 307) it had already been referred to *Scruparia*, of which it is the genotype, by Oken in 1815. Hastings (1941, 465) has shown that the *Eucratea chelata* of Hincks and many subsequent authors in fact includes two species, *Scruparia chelata* (Linné) and *S. ambigua* (d'Orbigny). The material here and that previously recorded from South Africa is much closer to the latter and the only difference is the longer stalk to the zooecium than is shown by Hastings (l.c., fig. 1) corresponding with Hincks' definition of *E. chelata* var. *gracilis* which Hastings regards as *S. ambigua*. *S. chelata* has not been recorded definitely from South Africa.

3. *Acanthodesia savarti* (Audouin)

Flustra savartii Audouin, 1826

Not previously recorded from South Africa. Present material from the hull of the *Sutherland* in Cape Town after a voyage including England, Colombo, Durban and Brazil.

This species as reported by various authors is widespread in tropical and subtropical seas and offers a wide range of variation. The material here examined falls within the described limits. One of its features is the presence of a proximal denticle on the cryptocyst. Here in the same colony this may be absent or present as a small projection or as a short lamina terminating in 4 or 5 teeth, but never so well developed as in some varieties. Further, there are no lateral projections from the cryptocyst as in the specimens figured by Harmer (1926, pl. XIII, fig. 8).

4. *Conopeum reticulum* (Linné)

Millepora reticulum Linné, 1767, 1284

Not previously recorded from South Africa. Present material from the hull of the *Empire Liddell* which had been in Cape Town about a month since dry-docking.

This material, encrusting the valve of a barnacle and a shell, appears to be referable to *Conopeum reticulum*. The size agrees quite closely with the specimen illustrated by Harmer (1926, pl. XIII, fig. 12). The triangular depressions found in some examples of this species are not discernible and the oral arch is slightly raised. Here and there, but not commonly, rounded projections occur in the triangular areas.

5. *Electra verticillata* (Solander)

Flustra verticillata Ellis and Solander, 1786, 15

Previously recorded from South Africa by O'Donoghue and de Watteville (1937, 12; 1944, 413) from St. James and cliffs, Port Nolloth, Bats Cave Rocks, East London. Present material from one mile off shore off Fish Hoek, False Bay, in 12 fms.; Kalk Bay, intertidal.

6. *Chaperia acanthina* (Lamouroux)

Flustra acanthina Lamouroux in Quoy et Gaimard, 1825, 605

Previously recorded from South Africa by Harmer (1926, 229) and O'Donoghue and de Watteville (q.v. for details 1944, 414). Present material from Kalk Bay, intertidal.

7. *Chaperia furcata* (Busk)

Membranipora galeata var. *α furcata* Busk, 1884, 64
Chapperia furcata Kluge, 1914, 673

Previously recorded from South Africa by Busk, Waters, Kluge, Marcus, O'Donoghue, O'Donoghue and de Watteville (q.v. for details 1944, 416). Present material from False Bay, off Fish Hoek, in 5–10 fms.

In one place a layer of the zooarium is overgrown by two other layers and yet, along the edge at any rate, they all seem to be alive. One well-protected piece possesses remarkably long spines and pedunculate avicularia. The lower pair of spines is by no means always furcate and never multifid.

The material possesses the deep colouration characteristic of the species which is removed in Eau-de-Javelle.

8. *Chaperia stephensoni* O'Donoghue and de Watteville

Chaperia stephensoni O'Donoghue and de Watteville, 1935, 205

Previously recorded from South Africa, as above, from Still Bay and Preekstoel. Present material from Strandfontein, intertidal. The colour of the living colonies is stated to be a dark plum and they retain colour on preservation.

9. *Amphiblestrum triangulare* (O'Donoghue)

Lepralia triangularis O'Donoghue, 1924, 43

Previously recorded from Survey Station 53 from 92 fms. and by O'Donoghue and de Watteville (1944, 424) from St. James on valves of a barnacle. Present material from Strandfontein, intertidal, on tubes of a worm. It was also dredged in Table Bay in 15½ metres.

Brown suggests (1952, 85) that this may be *Amphiblestrum trifoliatum* (Wood) which has been recorded from the Northern hemisphere and from New Zealand as a recent species. While it is obviously congeneric I doubt if it is conspecific and prefer to leave it pending comparison with the type and other material. Among other points the zooecia figured by Brown are only about ¾ the length. He states that the zooecia are separated by grooves whereas in the present material they are separated by raised margins which are very conspicuous when cleaned with Eau-de-Javelle. The avicularia vary little in size, no zooecium has been found with more than one, and they are not 'sessile', if by that Brown means on the surface. They are always borne upon very distinct subconical projections. These projections are

as tall as the ooecia to which they appear to be attached when an ooecium is developed on the frontal of a zooecium immediately distal to a fertile one.

10. *Steganoporella buski* Harmer

Steganoporella buski Harmer, 1900, 272

Previously recorded from Port Elizabeth and Algoa Bay by Harmer and *vide infra*. Present material from Umhlanga Rocks, Natal

Harmer (l.c.) pointed out that Busk's original material of *S. magnilabris* included two species *S. magnilabris* and another which he termed *S. buski*. The specimens for which Busk gave the locality Algoa Bay in fact belong to the latter. A reinvestigation of the material referred to *S. magnilabris* by O'Donoghue and de Watteville (1935 and 1944) shows that it belongs to *S. buski* and so the localities need to be transferred. So far then *S. magnilabris* does not appear to have been recorded from South Africa.

11. *Menipea crispa* (Pallas), figs. 1 and 2

Cellularia crispa Pallas, 1766, 71

Cellaria cirrata Ellis and Solander, 1786, 29; pl. LV., fig. D

Menipea cirrata Busk, 1852, 21; pl. 20, figs. 1 and 2.

Menipea crispa Marcus, 1922, 11

This, the genolectotype, whose synonymy has been dealt with by Marcus (1922, 11) and Harmer (1923, 313) has been recorded previously from South Africa probably by Pallas (l.c.) by Busk, Marcus, O'Donoghue, Hasenbank, O'Donoghue and de Watteville (q.v. for details 1937 and 1944) and Hastings (1943) from outside Saldanha Bay. Present material from Table Bay in 5–10 fms., a mile off-shore between Blaauwberg and Milnerton, Table Bay 15½ metres and Kalk Bay, intertidal.
ANCESTRULA. Ancestrulae of *M. crispa* were found settled on a colony of *Onchoporella buski* from 5 to 10 fms. in Table Bay where *M. crispa* was also dredged. The ancestrula is a short, curved, horn-shaped structure somewhat like that of *M. patagonica* (Hastings, 1943, 334), but with a more elongate stalk and the opesia is at a slight angle more like that of *M. flagellifera* (Hastings, l.c.). As a rule there are 9 spines of which the longest is in the mid-ventral line. In one example this spine was double. The others are fairly evenly spaced and not in groups as in *Bugula calathus*. The spines are as long as or longer than the body and slightly incurved.

The first zooecium arises from the mid-dorsal line a little way below the margin. It is somewhat like the adult in the position and size of the opesia but unlike it in possessing 5 spines instead of only 2 or 3 and in not having a median avicularian process arising from just below the middle of and projecting at least half-way up the front of the opesia. Instead of this process there is, in the same position, a small eminence with an avicularium. The median process is not developed until the fourth or fifth zooecium and the first internode is shorter than the typical one.

12. *Menipea triseriata* Busk

Menipea triseriata Busk, 1852, 22; pl. xxiii, figs. 2, 3, 4
Cellularia triseriata O'Donoghue, 1924, 31

Previously recorded from South Africa by Busk, Hasenbank, Harmer, O'Donoghue, O'Donoghue and de Watteville (q.v. for details 1937 and 1944), and by Hastings (1943) from Saldanha Bay. Present material from Table Bay in 5–10 fms., a mile off-shore between Blaauwberg and Milnerton.

This species is interesting in that it possesses internal avicularia. The branches of the zooarium are biserial at their bases but after a short distance, about 5 zooecia, become triserial by the interposition of a median row of zooecia. Each lateral zooecium bears a single marginal avicularium on its outer distal corner and these vary but little in size. The same zooecia also have a frontal avicularium on the proximal end near the inner margin. The first of the median row of zooecia bears a single median avicularium on the proximal end but the remainder have a pair of proximal frontal avicularia.

An internal avicularium was first described by Levinsen (1909, 139) in *Menipea roborata* and their occurrence was dealt with by Harmer (1923, 318) who records them in *M. triseriata*. All the species in which Harmer found them belong to the genus *Menipea* but by no means all members of the genus possess them. An internal avicularium in the present material is the same in size and structure as the ordinary one but, instead of being on the outside and therefore projecting into the surrounding water, it is developed on the inside of the zooecial wall and thus projects into the cavity of the zooid like a mirror image. It is difficult to see what function is served by this complete inversion. Internal avicularia do not appear in any constant or regular arrangement. In the material here examined the single median avicularium of the first of the median row of zooecia is internal in a few instances but none has been seen among the paired avicularia of the remaining median zooecia. Infrequently the frontal avicularia on all the lateral zooecia of an internode may be normal or internal but commonly they are mixed in varying proportions.

13. *Bicellariella chuakensis* (Waters)

Bicellaria chuakensis Waters, 1913, 467
Bicellaria capensis O'Donoghue, 1924, 32

Harmer (1926, 421) in a footnote suggested that the material described as *Bicellaria capensis* was probably the *B. chuakensis* of Waters. The examination of further specimens in the present collection confirms this. Waters describes an ovicell but none has been found.

Previously recorded from South Africa by O'Donoghue as above from off Cape Infanta in 20–40 fms. Present material from Table Bay, a mile off-shore between Blaauwberg and Milnerton.

14. *Bicellariella ciliata* (Linné)

Sertularia ciliata Linné, 1758, 815

Bicellaria ciliata Hincks, 1880, 68

Levinsen (1909, 431) noted that *Bicellaria* Blainville (1830) had been anticipated by Macquart (1823) for a genus of flies and proposed that the name should be altered to *Bicellariella*.

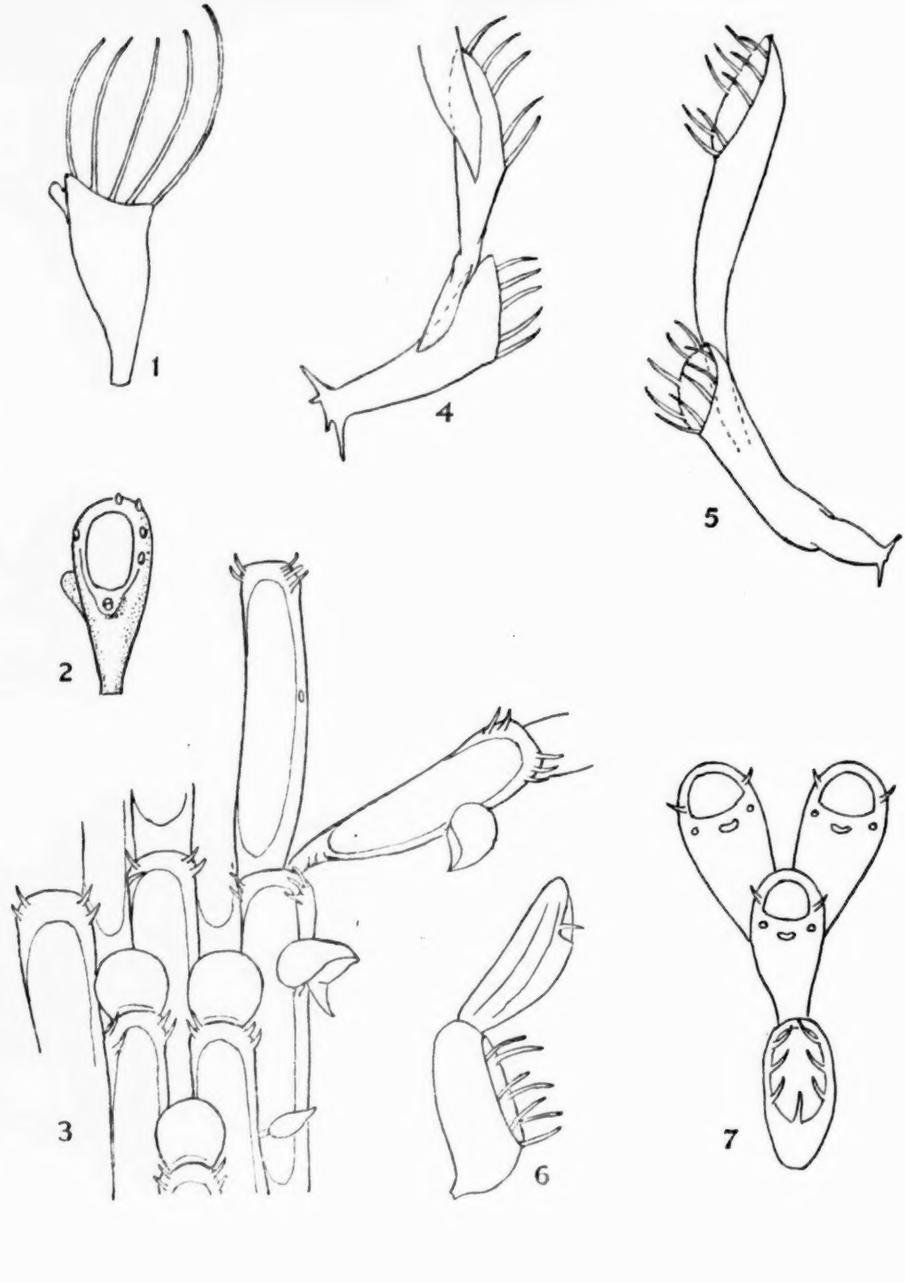
Previously recorded from South Africa by Hincks (l.c.) and O'Donoghue and de Watteville (q.v. for details 1935 and 1944). Present material from Umhlanga Rocks, Natal.

Hincks says that the South African material is a distinct variety characterized by the avicularium being of larger size, the inferior spine being more or less lateral, the zooecium being shorter and therefore more closely packed because the portion below the joint is much less elongated. These seem to be particular to the specimens examined by Hincks for a certain amount of variation in all these respects is exhibited by the present examples. In some the zooecia are just as long as the longest figured by Hincks, in some the avicularia are smaller, in some the inferior spine is median and in Hincks' own illustration (1880, pl. 8, fig. 1) this spine is shown as lateral sometimes. There does not appear to be sufficient constancy of difference to justify the establishment of a variety for the South African material.

Genus *BUGULA*

Twenty of the tubes in this collection contained material gathered from the hulls of ships in Cape Town or, three of them, from plates immersed for different lengths of time in Table Bay. Four of the specimens, including one from a plate, are encrusting forms; the remainder are erect. These erect forms include only three species of Bugula, viz. *B. avicularia*, *B. calathus* and *B. neritina*. These species have been recorded previously from South Africa. Mr. M. I. Crichton collected them in 1937 from a whaler *Sigma* that had been moored in Saldanha Bay for two years and nine months and in Cape Town for three months. The first and last have a world-wide distribution, and *B. calathus*, known from Britain and the Mediterranean, was recorded from South Africa in 1914. Thus the present collection gives no indication of the introduction of new species. The fact that the colonies of *B. calathus* on the hull of the *Transvaal*, which had been in Cape Town three and a half to four months, are, if anything, smaller than those on a plate that had been immersed for two months, may indicate that its colonization occurred in Cape Town, if they are representative samples.

In a preliminary examination there appeared to be more than three species of erect forms in these twenty tubes but the appearance of a Bugula colony is affected by a number of factors. First, its age; a young colony is usually clean and its short turgid branches give an impression of sturdiness that is lacking when the branches get longer. Further, if the branches are plentifully furnished with ovicells their appearance is different from those without them. Then, too, possibly due to age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(since it is most noticeable in larger colonies), or possibly the result of a physiological state, colonies are encountered in which almost all the polyps are in the resting 'brown body' stage. The colony then appears coloured but translucent and the branches flaccid. Secondly, the colony may be overgrown with other organisms, plant or animal, which alter both appearance and colour. One specimen from *Labrus*, which had been in Cape Town for about five years since the last time in dry-dock, was *B. Calathus*. It was in the 'brown body' stage and most of its branches were completely overgrown by *Bowerbankia gracilis* var. *caudata* and a creeping campanularian Hydroid so that superficially it bore little or no resemblance to young clean colonies of the same species.

15. *Bugula avicularia* (Linné)

Sertularia avicularia Linné, 1758, 809

Bugula avicularia Oken, 1815, 90

Previously recorded from South Africa by O'Donoghue and de Watteville (1944, 419) from St. James. Present material from a number of hulls of vessels in Cape Town, from the *Sigma* in 1937 and from plates that had been immersed for thirteen weeks in Table Bay.

16. *Bugula calathus* Norman, figs. 3, 4, 5

Bugula calathus Norman, 1868, 218

Bugula flabellata Hasenbank, 1932, 330

This species was recorded by Kluge (1914, 636) from South Africa. Subsequently Hasenbank (l.c.) recorded *B. flabellata* from Plettenberg Bay and, following this identification O'Donoghue and de Watteville (1935, 208) recorded the same from Cape Town Pier. Hastings (1943, 427) pointed out that in both instances it is really *B. calathus* and herself records it from South Africa. The record of *B. flabellata* by Kirchenpauer quoted by Hincks is most probably *B. dentata* (q.v.) so that *B. flabellata* (J. V. Thomson) has not yet been recorded from South Africa.

FIG. 1. *Menipea crispa* (Pallas) × 73. Ancestrula, lateral. The spines, 9 in number, are shown on one side only. On the dorsal surface is the bud of the first zooecium.

FIG. 2. ——. The first zooecium × 73. The bases only of the five spines are shown and the eminence bearing the small avicularium.

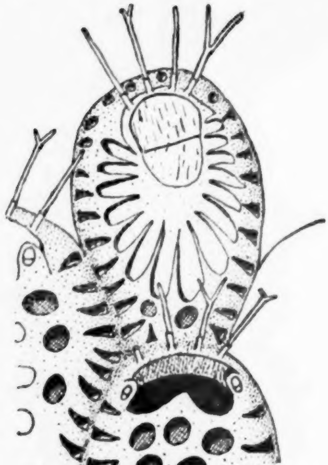
FIG. 3. *Bugula calathus* Norman × 47. Part of a branch to show unequal division in branching. The main branch carries on with 5 zooecia in a transverse row. The origin of the side branch is a single, normal zooecium arising from a constricted 'stalk'; the next zooecium is also single but is followed by two.

FIG. 4. —— Ancestrula, lateral × 47. Short type to show origin of second, similar individual and the latero-dorsal origin of one of the paired, more adult, zooecia. The spines, 9 in number, are shown on one side only.

FIG. 5. —— Ancestrula, oblique × 47. Long type to show the arrangement of the spines round the opesia.

FIG. 6. *Onchoporella buski* Harmer × 47. Ancestrula, semi-lateral to show the arrangement of the spines and the origin of the first zooecium more like the adult.

FIG. 7. —— Ancestrula and first three zooecia × 47 ventral view.



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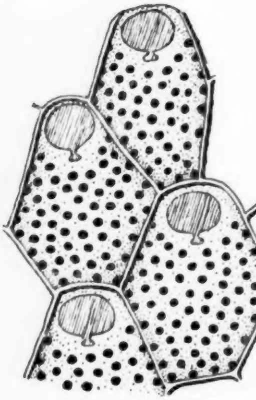

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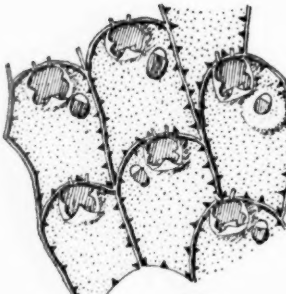

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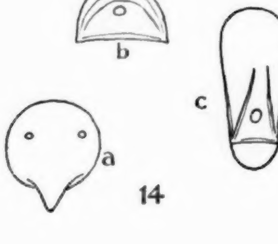

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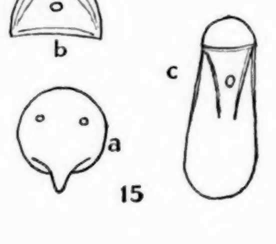

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A certain amount of variation is noticeable in this material. The zooecia vary from 3 to 9 in a transverse row. The same colony may vary in this respect and some branches contain mainly 7–8–9 zooecia in a row and other branches, equally long, contain mainly 3–4 but do not exceed 5. Further, whole colonies may vary in the same respect so that the one with the wider branches appears a sturdier form than the other. By no means all the zooecia, marginal or internal, bear avicularia. When present the avicularium arises from the opesia from one-third to one half-way down from the distal end. While the avicularia on the marginal zooecia vary in size they are never so small as those on the inner zooecia. The commonest arrangement is 2 spines on each distal corner. Sometimes there are three on the outer corner of a marginal zooecium. They may be well developed, i.e. as long as the width of a zooecium or, one, or both, may be so short as to be only just discernible. So a branch or colony with relatively few avicularia and tiny spines appears quite different from one with plenty of avicularia and long spines.

Hincks (1880, 82) remarks that the zoarium arises from a fibrous base in a cup shape. This is particularly true of young colonies but not so clear in older larger colonies and does not show if in collecting the base is left behind.

Ordinarily when a branch divides the number of zooecia in the transverse rows at the beginnings of the two daughter branches together is 2 more than in the parent branch. Very occasionally the division may be quite unequal and one branch may start with only a single zooecium while the other may have 4 or 5. The resulting appearance is of the parent branch carrying on with an 'adventitious' branch attached to it. The single zooecium may give rise to another single one before a double line is established. Such a branch seems to be loosely attached to the parent and is noticeably narrower than its immediate neighbours. The single initial zooecium usually arises from the outer distal corner of a parent one but in one instance it arose from the median zooecium immediately below a bifurcation. Although arising in similar positions, these are obviously not the same as the initial zooecia of the true adventitious branches described by Hastings (1943, 427 et seq.) in *B. calathus*, *B. cucullata* var. *cuspidata* and *B. dentata* nor by Marcus (1938, 68) in *B. turrita*. These are ancestrula-like individuals whose successors show the usual gradation to zooecia of typical form whereas in the present examples the initial zooecium is an ordinary one with the normal number of spines and an avicularium

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FIG. 8. *Stomachetosella balani* (O'Donoghue and De Watteville) × 47. Part of zoarium near the growing edge to show primary orifice.
FIG. 9. —— Operculum × 73.
FIG. 10. *Escharoides contorta* (Busk) × 47. A zooecium at the growing edge with jointed, branched spines and calcification little advanced.
FIG. 11. ——. Portion of zoarium × 47 showing secondary orifice, peristomial avicularia and ooecia with characteristic radial perforations.
FIG. 12. *Parasmittina natalense* sp. nov. × 47. Portion of zoarium with an avicularian chamber on the right-hand zooecium.
FIG. 13. ——. Orifice and peristome × 93 to show lyrula and cardelles.
FIG. 14. *Cellepora cylindriformis* (Busk) × 73. a, operculum; b and c, mandibles for identification, from material referred to *Costazia costazii* in 1935.
FIG. 15. ——. a, operculum; b and c, mandibles × 73. From present material.

on the outer side and, in one instance, it also has an ooecium as had the second in the line.

ANCESTRULA. The ancestrula is of an elongated infundibuliform vase shape. The opesia is slightly oblique and bears 9 spines round its margin (11 were seen in one example). The ancestrulae vary in length and are attached by a group of short basal projections. One spine is mid-ventral and the first pair are moderately close to it, one on each side. The other three pairs are more or less evenly spaced. The ancestrula is followed by a similar individual which arises well down its back but in the second the opesia is more oblique and the ventral 3 spines are separated from the others by a wider space but there are still 9 spines. From the latero-dorsal regions of this second individual arise two zooecia which approximate more closely to the adult in the arrangement of their spines, i.e. the ventral group has disappeared and the remainder are reduced to 2 pairs or to a 2 and a 3 at the outer corners but the opesia, while still more oblique, does not occupy so much of the front as in the adult. These two zooecia diverge and each gives rise to a branch, but avicularia do not usually appear until the second zooecium up the branch or even later. There are variations from this general arrangement: the ancestrula may be followed by 2 infundibuliform individuals, or it may be more like the second form described above (with opesia quite oblique, the ventral group of spines separated from the others and 2 zooecia arising from it). Marcus (1938, 68; pl. xv) shows an infundibuliform ancestrula of *B. turrita* with at least five subsequent generations with no noticeable change of form even after branching.

The ancestrula may settle on any part of the 'parent' colony, the dorsal surface, the lateral surface or even on the frontal or opesia, and in one instance a very long ancestrula is borne on the frontal of another normal ancestrula which has already given rise to its successor. Marcus (1938, 69; pl. xvii) describes in *B. plumosa* an ancestrula very similar to that here described, with 9 spines similarly arranged, which has settled at the distal end of a lateral zooecium. Of course most larvae must be carried away from the colony producing them, a method for the dispersal of the species; some may settle on their parent zooarium but others settle even upon another species.

The material from the hull of the *Pretoria* which had been in Cape Town five to six months after dry-docking was noteworthy for the number of ancestrulae settled on it.

17. *Bugula dentata* (Lamouroux)

Acamarchis dentata Lamouroux, 1816, 135

Bugula dentata Busk, 1852, 46

Previously recorded from South Africa by Krauss, Busk, Kirchenpauer, Waters, O'Donoghue, Harmer, Hasenbank, O'Donoghue and de Watteville (q.v. for details 1944, 419). Present material from Umhlanga Rocks, and Tiger Rocks, Isipingo, Natal.

It has been pointed out by Marcus (1938, 72) and Hastings (1943, 427) that Kirchenpauer's record of *B. flabellata* quoted by Hincks (1880, 81) is actually *B. dentata.*

The constant three spines on the outer distal margin are very well marked in all the South African material examined. The distal spine is always the shortest and quite frequently but not always the proximal one is the longest and may be very long.

18. *Bugula neritina* (Linné)

Sertularia neritina Linné, 1758, 815

Bugula neritina Busk, 1884, 42

Previously recorded from South Africa by Marcus (1938, 66), Hastings (1943, 430) from the Cape of Good Hope, and O'Donoghue and de Watteville (1944, 419) from St. James. Present specimens from the hulls of ships in Cape Town Harbour and from that of *Sigma* in 1937. This species is not infrequently found on hulls of vessels; this may account for its cosmopolitan distribution. There is a certain amount of variation in the development of the 'shoulders' at the distal ventral corners. Sometimes they are more or less square and at others they are carried out into sharp triangular points as illustrated by Marcus (1938, pl. xiii, fig. 34) but never into spines. Considerable variation in this respect may be found in one small colony. Some of the colonies from *Sigma* had many more ooecia than any other material examined.

19. *Beania magellanica* (Busk)

Diachoris magellanica Busk, 1852, 54

Beania magellanica Waters, 1904, 28

Previously recorded from South Africa by Jullien, Waters, Marcus, O'Donoghue, Hasenbank, O'Donoghue and de Watteville (q.v. for details 1944, 419). Present material from 5 to 10 fms., a mile off-shore between Blaauwberg and Milnerton, Table Bay.

The material consisted of several small colonies growing over and closely attached to *Menipea triseriata.* The rooting fibres arising from the middle line of the dorsal surface of the zooecia nearer the distal end were firmly attached to any part of the zooecia of *M. triseriata.*

20. *Beania vanhöffeni* Kluge

Beania vanhöffeni Kluge, 1914, 647

Beania paucispinosa O'Donoghue and de Watteville, 1935, 208

Previously recorded from South Africa by Kluge (l.c.) from Simon's Bay; by O'Donoghue and de Watteville (l.c. and 1944, 420) from Seaforth and Kalk Bay Pier; Hastings (1943, 412) from Cape of Good Hope. The present material is from Kalk Bay, intertidal.

It resembles *Beania magellanica* in growing over and being attached to a species of *Menipea*, in this case *M. crispa*.

This species was recorded under the name *B. paucispinosa* but Marcus (1937, 63) and Hastings (1943, 413) express the opinion it is *B. vanhöffeni*. This appears to be correct. Hastings points out that the erect distal marginal spines are not so stout as in Kluge's specimen. The present material is interesting in respect of the variation of the spines shown in the four colonies. In one the development of the spines is similar to that previously described. In another the spines, including the distal erect ones, are better developed so that the typical condition is more nearly approached. The remaining two colonies however vary in the reverse direction and the spines are much reduced. Hasenbank (1932, 336) describes comparable variation in the spination of *Dimorphozoon nobile*.

SUB-ORDER CHEILOSTOMATA

SECTION ASCOPHORA

21. *Hippothoa hyalina* (Linné, 1767)

Hippothoa hyalina Waters, 1900, 70

Cellepora hyalina Linné, 1767, 1286

Previously recorded from South Africa by Busk, Hincks, O'Donoghue, O'Donoghue and de Watteville (q.v. for details 1937, 15; 1944, 424). Present material from intertidal zone, Kalk Bay, and a marked, opaque, umbonate, tightly packed variety from 1 mile off Fish Hoek in 12 fms.

Genus *CATENICELLA*

The name of this genus calls for brief notice. Savigny in 1811 (*fide* d'Orbigny) on Pl. 13 illustrated two species of Bryozoa under the name 'Catenaires' called Contei and Lafontei but this is not acceptable because 'Catenaires' is vernacular. Confusion has arisen in the subsequent treatment of these two species which are not conspecific. Lamouroux (1824) apparently satisfactorily extablished a genus *Catenaria* with its type *C. contei* but what he did not realize and what was commonly been overlooked since is that *Catenaria* had already been used by Zeder in 1800 for a genus of Cestodes. In 1826 Audouin gave an explanation of Savigny's plates and, without referring to Lamouroux (1824), placed Contei and Lafontei with *Sertularia loricata* Linné (1758) in the genus *Eucratea* Lamouroux (1812) of which the type is *E. loricata* (Linné). Neither belong to this genus. Blainville (1830, 426; not 1834 as generally quoted) stated that Savigny had established a genus *Catenaria* but, without giving a reason, changed the name to *Catenicella* and the name of the species from *C. contei* to *C. savignyi* (the latter change is not permissible). Thus the genus *Catenicella* was adequately established with *C. contei* (Lamouroux ex Savigny) as type. There

is thus no need for the introduction of *Vittaticella* Maplestone (1901) for this genus, as was done by Waters (1909, 130) and some subsequent authors, and it certainly cannot revert to *Catenaria* as suggested by Levinsen (1909, 213).

In 1850 d'Orbigny (p. 43) accepted the genus *Catenicella* Blainville with *C. contei* and erected another genus (p. 42) *Catenaria* with its first species *C. lafontei* = *Eucratea lafontei* Audouin (1826). It is a satisfactory genus but the name Catenaria cannot stand for reasons given above. Busk (1852, 14) placed this species in his genus Alysidium of which *A. parasiticum* is the type but in 1884 (p. 14) withdrew it as it obviously did not belong there and re-established the genus *Catenaria* citing *C. lafontei* (Audouin) as the type. Levinsen (1909, 274) deliberately gave a new name, *Savignyella*, to what he called d'Orbigny's genus *Catenaria* and gave *C. lafontei* as the type. Thus a satisfactory genus had been found for the second of Savigny's 'Catenaires' and the new name *Catenariella* proposed by Strang (1928, 37) for d'Orbigny's genus is unnecessary and is a pure synonym of *Savignyella*.

22. *Catenicella elegans* Busk

Catenicella elegans Busk, 1852a, 361

Vittaticella elegans O'Donoghue and de Watteville, 1944, 421

Previously recorded from South Africa by Busk (1852a, 361; 1852, 10; 1884, 12), from Algoa Bay, and by O'Donoghue and de Watteville (above) from Isipingo Beach, Durban, and Shelly Beach, East London. Present material from Tiger Rocks, Isipingo, Natal.

The material here examined exhibits a certain amount of variation and does not conform strictly to Busk's and Levinsen's descriptions and figures. Busk in all his three figures shows the bizooecial internodes separated by at least two unizooecial internodes. In all the material examined from three localities in South Africa by far the most common arrangement is for uni- and bizooecial internodes to alternate. Rarely one bizooecial internode may be followed by another and occasionally a number, up to five, unizooecia may occur in succession. The largest number encountered was four unizooecia, then a gonozooecium with its ooecium, the covering zooecium and one more normal unizooecium with nothing to suggest that it was a terminal member. On the whole the longer runs tend to be towards the ends of the long branches of the colony.

The second point concerns the scapular chambers. Levinsen (1909, 255) states that the scapular chamber is everywhere developed as an avicularium and he figures them as not at all prominent. This does not hold for the present material. Not infrequently no avicularium is developed and the scapular chambers are carried out into a pair of prominent projections on each side that resemble those illustrated by Levinsen (pl. xxi, fig. 1a) in *Catenaria cornuta*. In the bizooecial internode the scapular chamber on the side of the daughter zooecium nearer the mother zooecium, whether it bears an avicularium or not, is not so prominent as that on the outer side.

The general relationship of gonozooecium, ooecium and covering zooecium is as illustrated by Levinsen for *C. elegans* (pl. xiii, figs. 3a and e) but there is no avicularium developed. The infra-scapular chamber on each side originates a little more on the ventral surface of the gonozooecium and passes ventro-distally as a slightly curved horn running parallel with but not touching the zooecium.

23. *Onchoporella buski* Harmer, figs. 6–7

Onchoporella buski Harmer, 1923, 314

Carbacea bombycina Busk, 1852, 52; pl. xlviii, figs. 4–7 (nec *Flustra bombycina* Ellis and Solander, 1786, 14).

Onchoporella bombycina Busk, 1884, 314

Previously recorded from South Africa by Busk, Levinsen, O'Donoghue and O'Donoghue and de Watteville (q.v. for details 1944, 423). Present material from Table Bay in 5–10 fms. a mile off-shore between Blaauwberg and Milnerton, and False Bay between Kalk Bay and Seal Island.

In 1852 Busk described some material from South Africa and identified it as *Carbacea bombycina* associating it with *Flustra bombycina* Ellis and Solander. There is no doubt from Busk's description and illustrations depicting the characteristic appearance of the zooecia, particularly the highly modified kenozooecia, that it is the species he subsequently termed *Onchoporella bombycina*, making it the genotype of a new genus. Busk, when he erected the genus *Onchoporella* recognized that his *Carbacea bombycina* was not the *Flustra bombycina* of Ellis and Solander. So as Harmer pointed out (1923, 314) it was necessary to give a new trivial name and he proposed *O. buski*. So far it appears to be recorded only from South Africa where it is not uncommon.

ANCESTRULA. The ancestrula is very short, slipper shaped with 7 spines fairly evenly distributed and not at all like that of *Bugula calathus*. In shape and number and arrangement of spines it is somewhat like that of *Notoplites tenuis* as described by Hastings (1943, 348) but differs in its development in that the first zooecium to arise from it is much more like the adult than in *N. tenuis*.

The first zooecium arises from the middle line close below the rim of the ancestrula by a slightly constricted stalk-like portion. It is much like an adult zooecium save for its base and for having only one pair of lateral perforations whereas in the adult there are at least two, usually three, and sometimes four pairs of such perforations. This condition of one pair persists in the first 6 or 7 zooecia. The first zooecium gives rise to a pair of zooecia. Each arises antero-laterally from the dorsal side and its base extends from near the middle line to well below the level of the aperture. The next zooecium arises in the middle line filling in the space between the lateral ones and extending beyond them. One or two examples have only one of the first pair of zooecia developed, followed by the median zooecium, thus leaving a space where the other lateral zooecium should have been.

24. *Stomachetosella balani* (O'Donoghue and de Watteville), figs. 8 and 9

Schizoporella balani O'Donoghue and de Watteville, 1944, 426

Previously recorded, as above, from St. James encrusting barnacle valves. Present material on worm tubes dredged in 27–28 metres between Kalk Bay and Seal Island and on clinker in 19–20 metres between Robben Island and Cape Town Docks.

Some of this material is somewhat younger and in a better state of preservation than that previously examined and so allows of modification of the original description. The primary orifice is oval and bears a narrow sinus in the middle of the proximal border. The sinus has parallel sides to start with and terminates posteriorly in a transverse expansion. The operculum is much the same shape as the orifice, i.e. it is an oval plate with a handle-like projection. The projection seems thicker than the plate and its free end is thicker still, transversely enlarged and often appears bicondylar. The primary orifice slopes downward from the frontal and with the increase of calcification the slope becomes more marked.

The irregular projections on the frontal may make their appearance before full calcification. One specimen on a piece of clinker is remarkable for the extent of secondary thickening. The irregular projections make their appearance almost at once and develop rapidly. They coalesce so that the whole of the frontal becomes one large irregular elevation and the secondary orifices, now no longer 'schizoporellid', lie in depressions between the elevations. This gives the whole surface of the zooarium a rough, knobbly appearance and, if it were not for the zooecia at the growing edge, it would be difficult to identify.

The secondary orifice not infrequently has the appearance of a 'schizoporellid' orifice with a wide sinus, but it is not regular. In early stages of calcification the margins of the secondary orifice may be raised in a narrow thin flange.

The ovicell lies in the proximal end and frontal of the zooecium in front and opens at the bottom of the peristomie. It projects slightly in the young parts of the colony and not at all in the older regions. The uncalcified area in the centre of the ovicell never becomes covered. Again no avicularia were observed.

While the ovicell and frontal show some resemblance to *Schizoporella perforata* Canu and Bassler (1929, 318) the other characters do not agree. It has closer affinities with *Stomachetosella sinuosa* (Busk) but differs in the shape of the primary orifice and the operculum *inter alia*.

25. *Emballotheca nivea* (Busk)

Schizoporella nivea Busk, 1884, 163

Schizoporella tenuis O'Donoghue and de Watteville, 1935, 214

Previously recorded from South Africa by Busk, Waters, O'Donoghue and de Watteville (q.v. for details 1935, 214; 1944, 424). Present material from between Kalk Bay and Seal Island in 27–29 metres.

In the description of this species (O'Donoghue and de Watteville 1937, 18) it was stated that there was a 'small, circular, slightly raised, flat-topped projection which although covered with chitin does not appear to be an avicularium'. This is not correct. It is an avicularium and the appearance just cited was due to insufficient cleaning. Some of the original material has been re-cleaned with Eau-de-Javelle and the tiny avicularia can be distinguished.

The species is subject to variation. The septal ridges between the zooecia may be well marked, or not discernible or their place may be taken by shallow grooves. Often the frontal below the orifice is smooth, but in other colonies it is raised into a median projection which in some individuals or colonies is enlarged into a distinct umbo. Apparently the presence of two tiny, almost circular avicularia, one in each distal corner, is a constant feature. There may be other similar avicularia on the frontal; in some colonies there may be two in one or both anterior corners; there is sometimes but not regularly or commonly an avicularium in one proximal corner but not, so far as here observed, in both; less commonly there may be other, small, adventitious avicularia in other places but always near the margin of the zooecium. Waters (1909, 168) in his description of the species from the Sudanese Red Sea figures zooecia with the same small avicularia in the distal corners but sometimes with a similar one in each proximal corner, or a small one in one corner and a much larger spatulate one in the opposite corner or a large spatulate avicularium in one corner only. He states that at one time he considered calling this var. *millanensis*. No such large avicularium has been found on any of the considerable amount of South African material examined. Waters' record of this species from South Africa is not a new one but a repetition of Busk's *Challenger* record.

Waters (1889, 29) states that the *Schizoporella tenuis* of Busk (1884, 165) is *S. nivea* with which Hastings (1932, 422) agrees. In view of this the material identified as *S. tenuis* by O'Donoghue and de Watteville has been re-examined. It is a small colony with no ooecia and not in very good condition but it is now considered to be *Emballotheca* (*Schizoporella*) *nivea*. Thus, *S. tenuis* has not so far been reported from South Africa.

26. *Escharoides contorta* (Busk), figs. 10 and 11

Eschara contorta Busk, 1854, 89

Mucronella contorta Busk, 1884, 155

Previously recorded from South Africa by Busk (1854) from Algoa Bay and in 1884 from Simon's Bay Cape of Good Hope, Waters (1889) from Algoa Bay; O'Donoghue (1924) from Cape Infanta and O'Donoghue and de Watteville (1937) from Oudekraal. Present material from between Kalk Bay and Seal Island in 27–29 metres; 1 mile off-shore at Fisk Hoek in 12 fms. and between Robben Island and Cape Town Docks in 19–20 metres.

Both of Busk's descriptions are very meagre and refer to fully formed bilaminar colonies with no ovicells which differ so considerably from younger, encrusting

colonies or even older ones with ovicells that these latter merit description. Some of the present specimens have greyish white, unilaminar encrusting zoaria.

The zooecia are large, approximately rectangular or less commonly polygonal. The primary orifice is nearly semicircular and around its distal margin are four spines, each consisting of a short basal piece and a much longer, more slender distal portion. The latter may be bifid near the top or from half-way down; it easily falls off, leaving the base. In its turn this disappears during secondary calcification so that no sign of spines is to be found in the slightly older parts of the colony. Calcification takes place rapidly by means of a series of projections growing in from the margin of the frontal which join up so as to leave a series of marginal areolae and oval ones over the ventral surface. The zooecia increase in depth so that the primary aperture comes to lie almost at right angles to the surface at the bottom of a deep peristomie. The frontal is carried up into a mucro; inside this in the middle line there appears to be a pointed denticle. In an oblique view, however, the denticle is seen to be a triangular ridge running down the peristomie. On each lateral margin of the peristome is a projection bearing an avicularium. This faces slightly inwards and its spatulate mandible opens obliquely outwards. These avicularia vary much in size from being small and inconspicuous to being very large and borne upon a marked prominence. A varying number of vicarious avicularia, all small, are scattered over the surface.

The rosette plates are large and oval and each is perforated by a large number of tiny pores. They lie in the basal region of the interzooecial walls. There are generally two or three vertical ovals in the proximal and distal walls and one, horizontal, in each lateral wall.

The hyperstomial ovicell may appear quite early. It is embedded in the frontal of the zooecium in front and opens at the bottom of the peristomie just outside the primary orifice. Over it the perforations and their separating ridges form a regular and striking radiating arrangement quite unlike the rest of the frontal. When the colony is heavily calcified almost the whole of the pattern on the ovicell lies in the distal wall of the peristomie. The presence of a vicarious avicularium in this region may upset the regularity of the radiating arrangement.

27. *Parasmittina natalense* sp. nov., figs. 12 and 13

This material comes from the intertidal zone at Strandfontein and Umhlanga Rocks, Natal, and is stated to have been pale yellow when alive.

The zoarium is encrusting and sometimes multilaminate. In the primary layer upon the substrate the zooecia tend to be regularly arranged but in the superposed layers they are more irregular and jumbled.

The zooecia vary in size and shape according to their position. In the primary layer they tend to be rectangular, arranged in rows and somewhat flattened. In the superposed layers they are often polygonal, irregularly arranged and more ventricose. They are separated by thin raised partitions which become less obvious as they become older when the frontal increases in thickness, more particularly laterally.

They are bordered by well-marked areolae and the frontal is finely granular. The primary orifice is not quite circular but a little wider than high and its proximal margin is straightened. There is a well-marked, broad lyrula and distinct cardelles. A thin, secondary peristome is developed which rises into a short projection in the mid proximal line, hardly large enough to be termed a mucro. Viewed obliquely this projection may obscure the lyrula but it generally only covers the middle portion. About half-way along each side there is a similar peristomial projection and distally the peristome becomes lower and bears two, short blunt spines (rarely only one is present). An avicularium is usually, but not invariably, present latero-proximal to the orifice. It is oval in shape with the mandible directed proximo-mesially and it is on the surface of the frontal. Sometimes a similar avicularium in the same position is borne upon a prominent, ventricose, avicularian chamber. No zooecium was found with more than one avicularium and no ovicell was observed.

This form, which appears to be undescribed, belongs to the genus Parasmittina as defined by Osburn (1952, 411). It is in some respects like *P. trispinosa* (Johnston) as described and figured by Osburn but the development of the peristome and the avicularium are quite different. The name *Parasmittina natalense* is suggested.

28. *Mucronella anatirostris* var. *spinifera* O'Donoghue

Mucronella anatirostris var. *spinifera* O'Donoghue, 1924, 47

Previously recorded from South Africa with no precise locality as above. The present material is from Strandfontein intertidal and was stated to be pale orange in life.

This material is older and more extensive than that in the previous collection. It possesses typical duck-bill shaped avicularia but they are more sparsely developed than in typical *M. anatirostris*; indeed some small colonies have none.

29. *Adeonella meandrina* O'Donoghue and de Watteville

Adeonella meandrina O'Donoghue and de Watteville, 1944, 425

Previously recorded from South Africa as above from Umhlanga Rocks, Durban; Isipingo Beach, Durban, and Bats Cave Rocks, East London. Present material from Tiger Rocks, Isipingo Beach, near Durban.

The present specimens came from nearly the same locality as one of the previous records. They consist of a number of pieces but no large colony as before. They are sufficient to indicate the general appearance of the zooarium. In these specimens two sessile avicularia on one zooecium occur more frequently than in the previous material but not invariably.

30. *Retepora tessellata* Hincks

Retepora tessellata Hincks, 1878, 358

Previously recorded from South Africa by Busk and O'Donoghue and de Watteville (q.v. for details 1937, 15). Present material from Kalk Bay and Strandfontein intertidal.

Again, as was discussed previously, the colonies show an interesting range from bilaminar to unilaminar condition.

31. *Cryptosula pallasiana* (Moll)

Eschara pallasiana Moll, 1803, 57

Cryptosula pallasiana Canu et Bassler, 1925, 33

This widespread species, which was for long known as *Lepralia pallasiana*, has not been recorded previously from South Africa. The present material is from the hull of *Windward* which had been in Cape Town about six months after being dry-docked and from plates that had been immersed in Table Bay for seventeen weeks.

The species is a variable one. In specimens from the Pacific Coast of North America it commonly has an umbo which may bear a small avicularium. The present material shows no sign of an umbo nor of an avicularium.

Genus *CELLEPORA*

The family Celleporidae is greatly in need of revision. In part this is due to the nature of the growth of many species which results in a thick, compact, encrusting colony or an erect coral-like zoarium both with the individual zooecia so jumbled up that it is difficult to determine their limits and structure. Until this has been done it seems better to retain a conservative attitude and here the generic name Cellepora is used in much the same sense as by Brown (1952). The following species is possibly referable to Schizmopora as used by Osburn (1952).

32. *Cellepora cylindriformis* Busk, figs. 14 and 15

Cellepora cylindriformis Busk, 1881, 351

Costazia costazii O'Donoghue and de Watteville, 1935, 214.

Previously recorded from South Africa by Busk as above from south of Agulhas (i.e. 35° 4′ S., 18° 37′ E.). The same record is repeated in the *Report of the Challenger*, 1884, and this is sometimes quoted as the original. It has been recorded as *Costazia costazii* by O'Donoghue and de Watteville (1935) and as *Cellepora avicularis* and *C. pumicosa* by the same authors (1944). Present material from Strandfontein intertidal, between Robben Island and Cape Town docks in 19–20 metres and Table Bay in 15½ metres.

The occurrence of several specimens of this species in the present collection led to a re-examination of the previous material. It is a variable species particularly

in respect of the number of spatulate avicularia and the number of ooecia. The frequency with which either are developed does not appear to be related to the age of the colony. The single zoarium described by Busk was cylindrico-conical and measured $\frac{3}{4}'' \times 0{\cdot}1''$. More commonly it is branched in an antler-like manner and one such colony was $1'' \times \frac{3}{16}''$ and had a spread of $1\frac{1}{8}''$. These branched colonies strongly resemble the *Costazia costazii* var. *erecta* of O'Donoghue and O'Donoghue (1923) and, overlooking the very few spatulate avicularia and ooecia in the first colony, led to its identification with this species. Subsequent examination of this material and of small specimens previously identified as *C. avicularis* and *C. pumicosa* has led to the conclusion that they are all referable to the *C. cylindriformis* of Busk and so *Costazia costazii*, *Cellepora avicularis* and *C. pumicosa* are not known to occur in South Africa.

Sub-order Ctenostomata

33. *Alcyonidium nodosum* O'Donoghue and de Watteville

Alcyonidium nodosum O'Donoghue and de Watteville, 1944, 428

Previously recorded, as above, from St. James, Lambert's Bay and Hotel Rocks, Port Nolloth. Present material from 23–24 metres between Kalk Bay and Seal Island.

As in all the above specimens this is encrusting the shell of the Gastropod *Comminella papyracea*. It is on a smaller shell than former specimens but again completely covers the shell. It seems to furnish another example of a specific relationship between a Bryozoon and another animal, recalling to a certain extent that between *Conopeum commensale* and the hermit crab *Petrochirus granulimanus* described by Kirkpatrick and Metzelaar in 1922.

34. *Bowerbankia gracilis* Leidy var. *caudata* Hincks

Bowerbankia gracilis var. *caudata* Osburn, 1912, 253

Previously recorded from South Africa by O'Donoghue (1924, 58) from St. James, False Bay. Present material from the hulls of ships in Cape Town. It is closely associated with *Bugula calathus* and *B. neritina*.

35. *Cryptopolyzoon concretum* (Dendy)

Cryptozoon concretum Dendy, 1889, 1

Previously recorded from South Africa by O'Donoghue and de Watteville (1944, 430) from Shelly Beach, East London. Present material from Isipingo Rocks, Natal.

A few small but undoubted pieces of this striking form were found associated with the rooting system of quite a large colony of *Catenaria elegans*.

36. *Penetrantia densa* Silén

Penetrantia densa Silén, 1946, 2

The family Penetrantiidae was erected to contain forms which burrow into the shells of mollusca. They were first recognized and described by Lars Silén. The type genus is *Penetrantia*, the type species is *P. densa* and the type locality is the Cape of Good Hope, on the shore 'at the lighthouses' in the shells of the gastropods *Burnupena delalandi* and *B. limbosa*. It is stated to be common. The second locality cited is the shore at Port Nolloth in *B. limbosa*.

The species has also been recorded intertidally from numerous localities in Southern California by Osburn and Soule (1953) but no species of mollusc is mentioned.

The present material is in the shell of *Turbo cidaris* from the intertidal zone at Strandfontein, False Bay. This shell of *T. cidaris* was probably included in the collection because it was partly covered with an encrustation that might have been a Bryozoon but actually it is a heavily calcified Hydrozoon, *Hydrocorella calcarea*.

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OBSERVATIONS ON THE FISH RIVER CANYON IN SOUTH WEST AFRICA

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(Read August 15, 1956)

The Geology and Geomorphology of the Fish River Canyon, as investigated during a reconnaissance expedition in January 1956, are briefy described, and certain evidence is put forward in support of the proposition that, despite previous assertions to the contrary by other authors, the double canyon consists of an erosional lower component carved by rejuvenation into the floor of the structural trough which forms the upper canyon. In so far as limited observations permit, certain tentative inferences are also drawn regarding the history of the canyon, as a basis for future, more detailed, investigation.

Introduction

The Great Fish River is unique in several respects among the watercourses of South West Africa. It is the only river within the boundaries of the territory which, at any rate in its middle and lower reaches, carries visible water throughout the year, though not always flowing on the surface. It derives its headwaters chiefly from the Nauchas Highland in western Rehoboth. Like the Auob and Nossob Rivers of the dry Kalahari to the east it flows, not seawards, but southwards parallel with the coast over a distance of some 500 miles, and joins the Orange River at a point about 70 miles from its mouth.

After passing from the northern mountain tract the river runs, with barely any incision, over an expanse of flat semi-arid country, falling in altitude from about 4,000 to 2,000 feet past Mariental, Gibeon, Keetmanshoop and Seeheim. Over this part of its course the river is fed by numerous right-bank tributaries draining higher ground to the west where the Naukluft and Tsaris Mountains build the Great Escarpment. Very little water is received from the few left-bank tributaries which drain the region to the east. Most of the area drained by the Fish is underlain by flat-lying beds of the Nama System which exert a strong structural control on topography.

South of Tses the river bed becomes distinctly incised into the Nama plateau surface. At the junction with the Gab River (fig. 1) the depth of incision is of the order of 150 feet. A few miles below the Gab junction the bed of the Fish River falls abruptly over two waterfalls and enters a spectacular gorge tract in which the incised meanders attain a maximum depth of some 2,000 feet below the Nama plateau surface. This is the Fish River Canyon proper, which continues its twisting course for over 40 miles to a point just upstream from Gochas Drift in the south, where the plateau-forming Nama sediments end abruptly. From Gochas Drift to

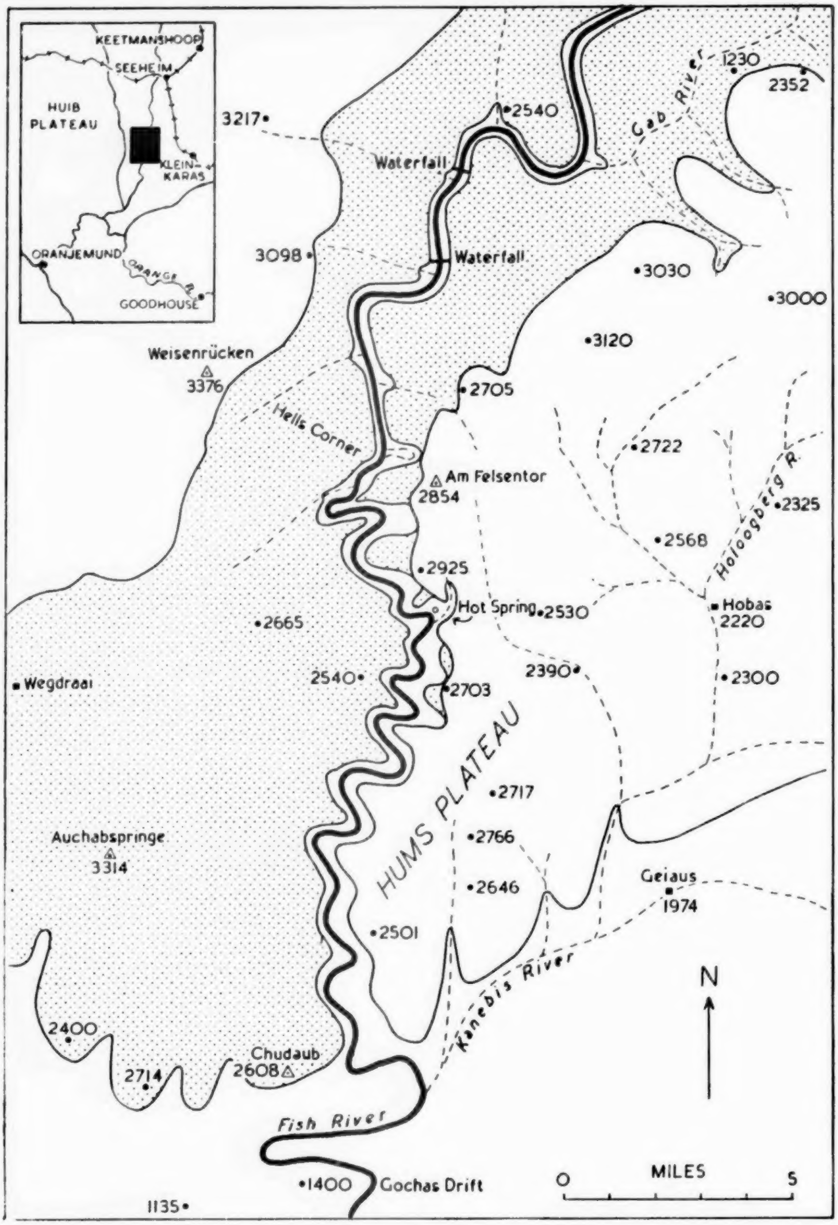

Fig. 1. Sketch-map of the Fish River canyon area in South-West Africa. Lower Plateau stippled. Physical features and spot heights (in English feet) based on unpublished map on a scale of 1:250,000 compiled by Surveyor E. K. Tredgold of Windhoek.

the confluence with the Orange River the Fish flows through a deeply dissected mountainous terrain cut in Archaean rocks.

The authors visited the Fish River Canyon as members of a reconnaissance expedition sponsored by the University of Cape Town and the *Cape Argus* in January, 1956. No detailed work was carried out but we believe that certain observations made during our visit should be placed on record as a contribution to the geology and geomorphology of this interesting region. Many deductions cannot be carried to their logical conclusion because of insufficient data, and this paper should be regarded rather as a basis for discussion and a stimulus for more detailed investigation over a wider area than as the record of a comprehensive survey.

Geology

The rocks exposed in the Fish River canyon area consist of more or less horizontally disposed sediments of the Nama System which rest unconformably upon an even surface cut across crystalline rocks of Archaean age. In the lower reaches of the canyon near Gochas Drift the base of the Nama sediments stands at a height of about 600 feet above the river bed but falls steadily, relative to river level, in an upstream direction. Exposures of Archaean rocks in the river bed give way to Nama at Hell's Corner.

The Archaean Basement rocks present a bewildering variety of structures and petrographic types. Biotite and hornblende gneisses predominate, in many places invaded and veined by a leucocratic granite which may well prove to be of arterite or venite type. Migmatitic rocks, amphibolites, garnetiferous schists, granulites, pegmatites and quartz veins add to the variety, while structures such as lit-par-lit intrusion, ptygmatic folding and all stages of digestion of xenolithic material are frequently shown to perfection on wind-eroded and polished surfaces. All these crystalline rocks are traversed by numerous dykes of pre-Nama diabase up to 60 feet in width. On the whole the gneissic and schistose rocks weather easily, most outcrops consist of friable decomposed material, and river erosion is able to proceed more rapidly in them than in the tougher Nama quartzites.

Overlying the basement crystalline rocks, the sediments of the Nama System consist of basal felspathic grits (including lenses of conglomerate and arkose) followed by fissile micaceous sandstones showing current bedding alternating with very hard sugar-grained quartzites. This succession, making up the Kuibis Series at the base of the System, is about 500 feet thick. A 50-foot band of hard quartzite at the top is succeeded abruptly by a bed of black limestone about 30 feet thick which marks the base of the overlying Schwarzkalk Series. On account of its persistence, resistance to weathering and conspicuous appearance among the lighter arenaceous rocks, this black limestone horizon provides a most valuable marker in unravelling structures. The higher horizons of the Schwarzkalk Series consist of fissile sandstones and shales but most of them have been removed by erosion in the area under consideration.

The chief geological interest of the area lies in the effects produced by post-Nama folding and faulting movements, and these effects are seen in their most

spectacular form from the end of the motor track which leads from the farm Hobas to the eastern rim of the canyon just south of Am Felsentor.

The regional structure of the Nama System hereabouts is one of gentle warping and flexuring, though the strata depart but little from their original horizontal attitude. The hard resistant quartzites of the Kuibis Series exert a strong structural control over physiographical development, building an extensive regional plateau (named the Hums Plateau along the eastern side of the canyon) which terminates abruptly in a series of krantzes to the west and north-east of Gochas Drift. This southern margin of the plateau is much indented by headward erosion of tributary streams. The structural plateau stands at an average elevation of about 2,500 feet above sea-level, rising along the outer rims of the canyon to 3,000 feet and higher. The ground surface falls away from the margin of the canyon at an inclination of some three degrees, about a roughly north-south axis of tilting.

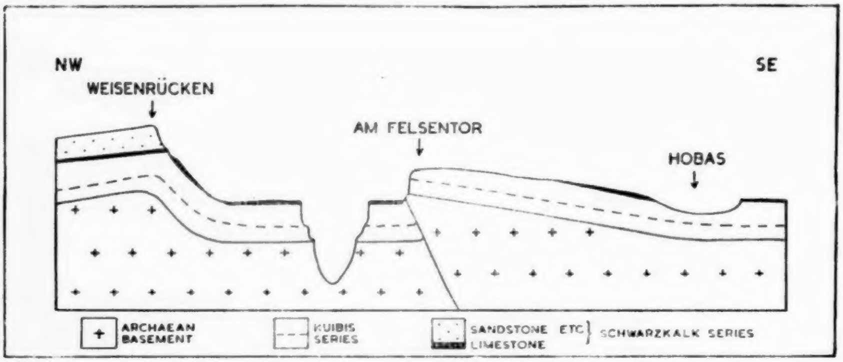

FIG. 2. Diagrammatic section across the Fish River canyon near Am Felsentor.

The composite nature of the canyon is seen to best advantage from the rim near Am Felsentor (fig. 2 and Plate VA). Two components can be clearly defined:

1. An upper canyon bounded by near-vertical scarps along the western and eastern sides, floored by a remarkably even plain which rises gently towards the south-west to become more or less coincident with the outer regional plateau.
2. A lower canyon which is a purely erosional feature produced by incision of the meandering course of the Fish River into the floor of the upper canyon. It becomes the dominant canyon form towards the south where the upper trough has ceased to exist as a separate component. The lower canyon is described in the next section.

The upper canyon is most typically developed between Am Felsentor and Weisenrücken (fig. 2). Here it is floored by a structural plain formed by the basal Schwarzkalk limestone which stands at a mean elevation of 2,500 feet above sea-

level. Towards the south-west the inner plain becomes floored by successively lower horizons within the Kuibis Series.

On the western side the bounding scarp rises abruptly to a height of 600 feet and more above the even floor to form a rampart which trends more or less NNE.–SSW. near Weisenrücken, but further south near the farm Wegdraai it swings westwards towards the Konkiep River. Structurally this western wall is a sharp monoclinal flexure now deeply dissected and well exposed by tributary erosion (Plate VIA). The monoclinal structure is particularly easy to follow by using as a marker-horizon the excellent exposures of the black Schwarzkalk limestone bed which is clearly seen to rise up from the floor of the upper canyon, forming a conspicuous dipslope up to the level where it once again resumes its near-horizontal attitude in the succession higher up in the western rampart. These features are shown clearly in Plate VIA. Indeed the structure of the western wall is strongly reminiscent of the monoclinal flexures bounding the Witputs trough as described and illustrated by Beetz (1924). Further work may well show the two tectonic troughs to be closely related, especially as the western wall of the Fish River trough swings away towards the Konkiep River, bringing its trend more in alignment with the WNW.–ESE. monoclinal axes of the Witputs trough.

The eastern boundary scarp of the upper canyon is no less conspicuous than the western but is lower, rising only 450 feet at most above the structural floor. It is formed by Kuibis quartzites dipping eastwards (i.e. away from the canyon) at low angles up to five degrees. The Kuibis Series thus lie several hundred feet above the Schwarzkalk limestone of the upper canyon floor and in fact the underlying gneisses are exposed in contact with the black limestone at the base of the eastern scarp (Plate VIB), pointing to faulting and not flexuring on this side. Owing to the excellence of exposures in this deeply dissected tract the fault can be clearly seen both in plan and in vertical section. It trends NNE.–SSW. and is a reverse fault with an eastward hade of 40°. Near Am Felsentor the throw is about 750 feet, decreasing southwards as the fault peters out. Along the fault plane the footwall beds have been sharply uptilted, in many exposures to a vertical attitude (Plate VIB). In addition the hanging-wall Kuibis sediments exposed in the eastern scarp show in several localities a sudden downward flexuring towards the west. This localized disturbance is probably due to differential drag along the fault plane, but the possibility cannot be excluded that the fracture developed from an incipient monoclinal flexure. Both Wagner (1916, p. 58) and Schwellnus (1941, p. 20) have pointed out that in the Karas Mountains to the east monoclinal folds are frequently resolved along the strike into faults.

Owing to obvious inaccuracies in the representation of the canyon on the map upon which fig. 1 had of necessity to be based, no attempt has been made to indicate the positions of the bounding fold and fault. Indeed there is good reason to believe that the structural pattern described above is, if anything, an oversimplification, but is valid for the canyon as a whole. In effect then, the upper canyon is a tectonic trough, bounded on the west by a sharp monoclinal flexure, on the east by a linear reverse fault, and developed by local compression accompanied by subsidence and uptilting of the bounding scarps.

The possible relationship between this structural trough and the Witputs trough has been discussed above. In addition it is interesting to note that, according to Dr. H. Martin (personal communication), the fault pattern between the Escarpment to the west and the Karas Mountains to the east shows a set of NNE. and NE. overthrusts (cf. Korn and Martin, 1951, Plate XI) and a distinct set of NNW. normal faults. The age-relationship between the two sets is unknown. On a regional scale it would appear that the Fish River tectonic trough forms the lowest central zone of a series of step faults (cf. Cloos, 1937, fig. 24), but again this may well be a misleading oversimplification. It is evident that the tectonic pattern of this interesting region, which is so well endowed with excellent three-dimensional exposures, warrants detailed structural study as a contribution to the problem of vertical tectonics (Brock, 1952, 1955).

Geomorphology

The Lower Canyon

From the waterfall below the Gab confluence to the southern end of the Hums Plateau the Fish River flows through a well-defined inner or lower canyon, which deepens southwards as the lower plateau into which it is carved rises to the level of the upper plateau.

It becomes immediately apparent to the observer that this canyon, in contrast to its upper counterpart, is an erosional feature, created by the incision of the mature river which flowed across the level surface of what is now the lower plateau. Below Hell's Corner (fig. 1), where the river has cut down to the basement rocks, this is revealed by a splendid belt of incised meanders which is a classic illustration of the processes of rejuvenation (Plate VB). So much does the canyon twist and turn that the straight-line distance of 20 miles between its two ends is increased to about 40 miles along the course of the river itself.

Rejuvenation is also indicated by the markedly youthful, ungraded long profile of the Fish River in this section of its course. Normally the river consists of a string of separate pools, often of considerable depth, which occupy depressions in the bed of the river. These are linked by smooth rock pavements over which the water is only a few inches in depth, or by masses of water-rounded boulders and pebbles. The latter become rapid tracts during flood, when the river exhibits the youthful characteristic of almost completely filling its valley floor. Bands of resistant rock create small temporary waterfalls, particularly in the upper reaches of the canyon, where structural terraces are also a feature along the river. The major break in this youthful profile is formed by the more northerly of the two waterfalls indicated on the map (fig. 1), which is said to be 85 feet high and forms the main knick point of the canyon. Above this waterfall the lower canyon is less than 150 feet in depth.

The few short, normally dry, tributary valleys which enter the main canyon exhibit these features to a correspondingly greater degree. A typical example is the

short left-bank tributary near the Hot Spring (fig. 1).* This descends steeply from the plateau by a series of rock pools and falls which have been worn smooth by flood water: as a result its knick point is almost impassable. The absence of grading creates a sharp contrast with the level plateau surfaces above.

While rejuvenation is clearly the causal factor, detailed field-work is required to determine the nature and origin of the canyon. At this stage it is possible only to indicate certain features observed during the various reconnaissances carried out.

In the first place, there are signs of vigorous meander migration, which is still in progress. This is best illustrated at Hell's Corner, where there is an excellent example of a cut-off incised meander (Plate VIIA). The old meander loop is incised about 450 feet below the level of the lower plateau, its smooth curve etched out in the horizontal quartzites and shales of the Kuibis Series, with the Schwarzkalk limestone again proving a useful marker-horizon. A well-defined meander core stands within the loop. The floor of the meander appears to be drained back to the river from both ends, and appears to stand everywhere less than 100 feet above the main river bed, indicating a relatively recent breakthrough across the neck.

The incipient stage of the same process of meander migration may be observed at a left-bank spur near Am Felsentor (fig. 1). Here characteristic basal sapping of the upstream side of the spur by the river has narrowed its neck to a mere ridge. The Nama has already been removed from this neck, leaving it at a lower altitude than the head of the spur, where its protective capping is still intact. This spur, and one or two others in the vicinity, exhibits the asymmetrical cross-section characteristic of lateral corrasion.

During the Fish River floods of late summer the lateral development of meanders indicated by these features can be observed in progress. On the outer side of river loops slopes are steepened and sapped by vigorous undercutting to the point where they become difficult to traverse, in contrast to the easy passage on the inside of bends. The river becomes a raging torrent well over 100 yards wide and travelling at a speed estimated at 12 to 14 knots. While the flooded river tends to fill its bed on straight reaches, stretches of floor remain above flood-level on the inside of true meanders, indicating lateral swing. During flood the rattle and roar of boulders in transit testifies to the carrying capacity of the Fish River in terms of instruments of corrasion. If the volume of noise is any indication, it seems probable that corrasion attains its maximum during the initial 'burst' of the flood, which scours out the accumulation of scree from the canyon floor.

* The existence of the hot spring in the bed of the canyon some four miles south of Am Felsentor, was pointed out to us by Mr. Louw of the farm Hobas. The position is indicated by Korn and Martin (1951, Plate XI) but hitherto no description of it seems to have been published.

Situated between two conspicuous clusters of date palms near the river on the east bank, the spring issues at a temperature of 134° F. with a strength estimated at approximately one cubic foot per second, the flow being at least as strong as that of the hot spring at Ai Ais further downstream. Although the water is highly charged with hydrogen sulphide, no encrustations of sulphur or mineral salts were found at the source which is nevertheless heavily overgrown with orange-coloured algae. Wind-blown sand overlying river-bed alluvium conceals the gneisses in the immediate vicinity, in which there seemed to be no conspicuous fissure or shatter zones.

There are also examples in the canyon of the classic wall sides of intrenched meanders, suggesting that in places downcutting is still rapid. It would appear that both vertical and lateral corrasion are active, each tending to characterize a particular reach of the canyon; an association which is not uncommon and may well reflect local differences in rock resistance. Certainly at Hell's Corner, where the rocks of the canyon floor change from Nama to Basement rocks, there is not only a marked deepening of the canyon, but also the true beginning of the meander belt itself. While detailed examination is called for, it may tentatively be deduced that there has been rapid downcutting until recent times, with the lateral development of meanders now beginning to play its part, and with rock character becoming important in determining the nature of local reaches of the canyon.

Particularly when making allowances for lateral development, the meander belt suggests maturity rather than old age in the erosion cycle of the Fish River at the onset of rejuvenation. The meanders form a relatively narrow linear belt which tends to hug the eastern side of the lower plateau, the meanders in places swinging underneath the edge of the upper plateau. Thus, east of the river, the lower plateau has been cut up into spurs, quite isolated from one another (fig. 1). West of the river, however, the incised meanders do not occupy the whole increased width of the floor resulting from the swing of the upper plateau edge away in a westerly direction, but remain in their narrow linear belt. That they do so cannot therefore be due to any restriction arising from the faulting and monoclinal folding of the upper walls; it is likely to represent simply a mature rather than an old-age stage in the erosion cycle at the time of rejuvenation. There appears to be no evidence of the swing of the whole *belt* of meanders, as characterizes the old-age stage in the erosion cycle.

Turning to the sides of the inner canyon, the first impression is of steepness, with a change at the base of the Nama from a 45° average slope of the less resistant Basement rocks to the vertical krantzes of the Nama beds, which are broken only occasionally by notches cut by small streams draining the lower plateau (Plate VB).

The lower canyon is primarily the result of erosion by running water, but other agents have also contributed to the landforms. Temperature changes have initiated decomposition among the granitic Basement rocks and granular disintegration among the sandstones of the Nama, the latter producing great quantities of sand in the canyon. This is turn has been whipped up by strong winds blowing up the canyon from the Orange River, at least in summer, and laid as a mantle of sand along the sides of the canyon floor, masking what appear to be depositional terraces in the lower reaches. These banks of blown sand, which are fringed with tall reeds along the river banks, in places divert the normally small river channel from side to side of the canyon floor, causing local undercutting of the walls of the canyon which may be unrelated to the main development of meanders (Plate VB). Away from ground friction the lower canyon sides have been scoured and etched by wind-blown sand and, noticeably at the exposed Hell's Corner, the harder bands in the Nama have been picked out by sandblasting. The slopes of the Basement rocks are strewn with scree fallen from the krantzes which, at least on the eastern side, are crumbled and dangerous as are those of the upper canyon.

The Plateau Surfaces

Whereas the lower canyon has been created and shaped by agents of denudation, the surfaces of both lower and upper plateaux have been determined by structure, as described above. Both are tabular surfaces, determined by the dipslopes of the Nama beds on which they are formed. Indeed it is remarkable how little denudation has moulded these plateau surfaces, in violent contrast with the part it has played in the lower canyon itself.

The lower plateau slopes evenly northwards at six or seven degrees below the horizontal until at the Gab confluence it is no more than 150 feet above the river. It is surfaced by Schwarzkalk limestone, except in the south, where there may have been more exposure to erosion. Plate VA shows a residual hill of sandstone standing perhaps 20 metres above a spur of the lower plateau; other residual features occur west of the river. These hills again suggest a stage of not later than maturity in the erosion cycle of the Fish River before rejuvenation. Apart from these few hills, the surface is remarkably even, and carries faint dendritic drainage patterns resulting from rain which falls for an average period of three or four weeks in a year. These minor tributaries flow towards the lower canyon, which they overhang; their northward trend is in response to the structural slope, to which they are consequent (Plate VIIB). Sharp notches have been cut in the lower canyon rim where the water is carried away. There is a great contrast between the tremendous fluvial erosion of the main river and the relatively faint visible indication of these tributaries. It is the latter which relate to the present aridity of the region, and the contrast underlines the dependence of the Fish River on its extensive upper catchment area.

The drainage of the eastern side of the upper plateau, while considerably more developed than that of the lower plateau, is still of a minor character. The violent rainstorms which occur during a few weeks in late summer cause sheet floods on these tabular surfaces; they do not result in marked stream dissection. Thus the Holoogberg River is only three or four feet below the level of the plateau at Hobas where, significantly, water-rounded stones are found a little way away from the stream bed itself; at Holoogberg Farm eleven miles upstream, the banks are no more than six inches high. The stream bed is sandy, and strewn with boulders. Stream dissection a few miles away from the upper plateau rim serves to increase slightly the slope away from the rim (figs. 1 and 2), but the slope is essentially a structural one. The rise up to the canyon edge is typical of the overthrusting associated with a reverse fault.

This structural nature of the slope is emphasized by the fact that the drainage channels near the canyon rim are consequent upon it. Fig. 1 reveals that from near the rim the drainage channels run south-eastward toward the Holoogberg River before being gathered into the Kanebis and returned to the Fish south of the Hums Plateau. Between the Gab and the Kanebis there is little drainage directly into the main river.

If drainage is relatively unimportant, weathering has left a distinct mark upon both plateau surfaces. The upper plateau is a sterile stone desert of quartzite debris weathered into fresh-looking, sharp-edged fragments under arid climatic conditions;

the grim aspect of the landscape intensified by an occasional solitary kokerboom (*Aloe dichotoma*). In the slight depressions of the Holoogberg drainage area some miles east of the canyon edge patches of sand mask the surface. Melkbos grows everywhere, except at the canyon edge, and minor drainage channels are picked out by small acacias. The lower plateau has a similarly weathered surface, although the limestone has broken down into smaller fragments than the quartzite, and there is very little vegetation of any kind.

The overriding impression left of the landforms around the Fish River Canyon is of the striking contrast between the youthful, erosional lower canyon and the mature, structure-dominated surfaces of the plateaux, where the river once flowed. The minor effect, under arid conditions, of fluvial erosion on the plateaux contrasts with the impressive demonstration of its power in the cutting of the lower canyon.

Conclusion

A reconnaissance of a small area does not permit speculation on the origin of the whole river system, nor should the local drainage be considered without reference to the whole. Nevertheless a possible sequence of events may be tentatively deduced. It would appear from the meanders that the Fish River in this part of its course originally flowed over a broad, level plain at a stage of maturity in its cycle. In response to the general continental uplift this surface became gradually uplifted, and the river began to cut down its bed to a lowered base level, its water, as now, being derived in the main from north of the region. As continental uplift in southern Africa is usually envisaged as being periodic rather than steady, detailed investigation of waterfalls here and upstream as possible multiple knick points, might prove profitable. It may well be possible to correlate these with the Augrabies Falls on the Orange River. During this uplift and rejuvenation fracturing occurred throughout the region, including the reverse fault and monoclinal folds now bounding the lower plateau. This lower plateau area, into which the river was eroding its canyon, was left behind in the general uplift, and gradually developed a northwards tilt in the opposite direction to the flow of the river. The Fish is therefore, at least locally, an antecedent stream, maintaining its course across a locally uptilting surface. This suggests the possibility that rejuvenation of the lower canyon was well advanced when the upper canyon was created, since without increased erosive power in the immediate vicinity a reversal of drainage would seem a likely response to the changing conditions. Detailed investigation is needed, however, to supply the answer to a number of questions on this interesting region.

Acknowledgement

The Society desires to acknowledge the receipt of a grant from the University of Cape Town towards the cost of publication of this paper.

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PLATE VA. View north-west from eastern rim of the upper canyon, near Am Felsentor, showing both lower and upper canyons and the river (bottom left). A residual hill of Schwarzkalk sandstone can be seen above the black limestone of the upper canyon floor, immediately above the foreground figure.

PLATE VB. The canyon at its deepest, near the hot spring. View westwards from eastern rim.

PLATE VIA. Telephoto view north-west from eastern rim of upper canyon, near Am Felsentor, showing dissected monoclinal folding (centre) picked out by Schwarzkalk limestone horizon which forms the structural floor of the upper canyon.

PLATE VIB. View southward along reverse fault which separates the upper plateau (left) from the lower plateau (right) along the eastern margin of the canyon just south of Am Felsentor. Fault plane is clearly seen, together with upturned Schwarzkalk limestone which forms large black outcrop (right foreground).

PLATE VIIA. The cut-off meander at Hell's Corner, with the meander core in the centre. Note the Schwarzkalk limestone marker-horizon.

PLATE VIIB.
Drainage channels on a left-bank spur of the lower plateau.

SOME FEATURES OF THE RELATIONSHIP BETWEEN MASS DEFECT AND MASS NUMBER

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Department of Chemistry, University of Cape Town

(Read September 19, 1956)

The variation of mass defect with mass number (naturally occurring isotopes only) has been examined using the critically revised mass data of Wapstra (1955). Three principal features may be distinguished; two can be correlated with significant $N = 50$ and $N = 82$, and the third, with isotope abundance distribution and variation (Ahrens, 1957). The mass defect vs. A route followed by the odd A isotopes is very clearly defined whereas the spread of points about the even A trend is quite considerable, particularly over the range $A = \sim 60$ to $A = \sim 140$. This is due to overlapping of trough-like distributions of mass defect for each value of even Z. Each such isotopic distribution approximates roughly to a parabola with one shortened limb.

Introduction

Attempts have from time to time been made in the past to examine the fairly regular relationship between mass defect and mass number for significant local detail; to seek, for example, the possible effect of a significant neutron number; or, in terms of the shell model, the effect of shell or subshell closure. Although certain distinct features have been noted before, there have been some difficulties because of lack and uncertainty of data. The position is now much improved and a considerable amount of good quality information is available for critical study. For our purpose the compilation of recommended values given by Wapstra (1955) will be used.

The discussion which follows is brief as the emphasis will be on graphical presentation. A subsequent paper (Cherry and Ahrens, unpublished) discusses some of the mass defect relationships, notably that involving variation of mass defect in *isotopes* (stable and unstable), in terms of the shell model of the nucleus.

Discussion

Variation of mass defect with mass number for all naturally occurring isotope species will be considered first and then the odd A's and even A's in turn.

Figure 1 relates mass defect to A for all nuclide species; even-even, even-odd, odd-even and odd-odd, are distinguished as indicated.

A notable feature about figure 1 is the discontinuity at $A = \sim 90$. Here the trend changes direction quite sharply. Leading up to this sharp discontinuity is a

development which starts at A = ~60 and continues to A = 90. This is a well-developed feature. A third distinct feature is the steepening of the trend at A = ~140. All isotope species participate in these developments. Other features may be recognized in figure 1, but they are not so well developed and will not be discussed here.

Though the trends and discontinuities of figure 1 are well defined, the spread of points is quite considerable. If odd A species (even-odd, odd-even) alone are considered (fig. 2) the spread of points about the general trend is very small and the route followed by the odd A's is clearly defined. For medium-weight isotopes—say, A = ~60 to A = ~140—the location of the odd A route is sometimes more or less centrally disposed with respect to the stability limits of the even A's.

The considerable spread of even Z — even N points in figure 1 may at first sight seem haphazard, but closer examination reveals some regular relationships, notably between A = 90 and A = 140, the mass range bounded by significant N = 50 and N = 82. Mass defect data are almost complete over this range and as many of the even Z elements contain large numbers of isotopes, it is possible to examine variation of mass defect for each value of Z (each element). This is shown in figure 3 (even-even isotopes only). For each value of Z, mass defect varies fairly regularly with N (and hence A), distribution is trough-like with the low N limb shorter than the high N limb. Then even-even 'structure' of the region between A = 90 and A = 140 is due to the overlapping of a series of such trough-like distributions. Distribution in Zr is not trough-like: only a high N limb is present and this dips steeply. This development is apparently due to the effect of significant N = 50. Variation of mass defect with A (even-even isotopes only) over the range A = 60 to A = 90 is shown in figure 4. There is again a tendency for trough-like distributions with the exception of Sr. Here one steep-ended limb only is present, as in the example of Zr, but sloped in a different direction. The different distribution in Sr is apparently again due to the presence of N = 50. The heaviest and the lightest isotopes respectively of Sr and Zr (Sr^{88} and Zr^{90}) are principal isotopes and have N = 50. For a discussion on isotopic variation of mass defect, see Collins, Johnson and Nier (1954).

The discontinuities at A = 90 (figs. 1, 2, 3 and 4) and A = ~140 (figs. 1, 2 and 3) may be correlated with the presence of significant N = 50 and N = 82, respectively. (In the shell model of the nucleus, shells IV and V are supposed to close at N = 50 and 82, respectively.) The regular variation between A = ~60 and A = 90 (figs. 1, 2 and 4) is not easily correlated with trends in nuclear properties. Some correlation may, however, be found with isotope abundance distribution and variation. Such distribution and variation is evidently sensitive to significant developments in the nucleus and the effects of well-established significant neutron numbers are marked (Ahrens, 1957). Starting at Ni^{58} (N = 30; Z = 28) and ending at N = 50 (A = ~90) is a regular and quite profound development (fig. 5; after Ahrens, 1957) and the only one of its kind; there is no sign of such a development preceding N = 82 (Ahrens, 1957). The correlation appears to be quite distinct but is not wholly satisfactory because all isotope species participate in the regular variation of mass defect with A between A = ~60 and 90, whereas only even-even

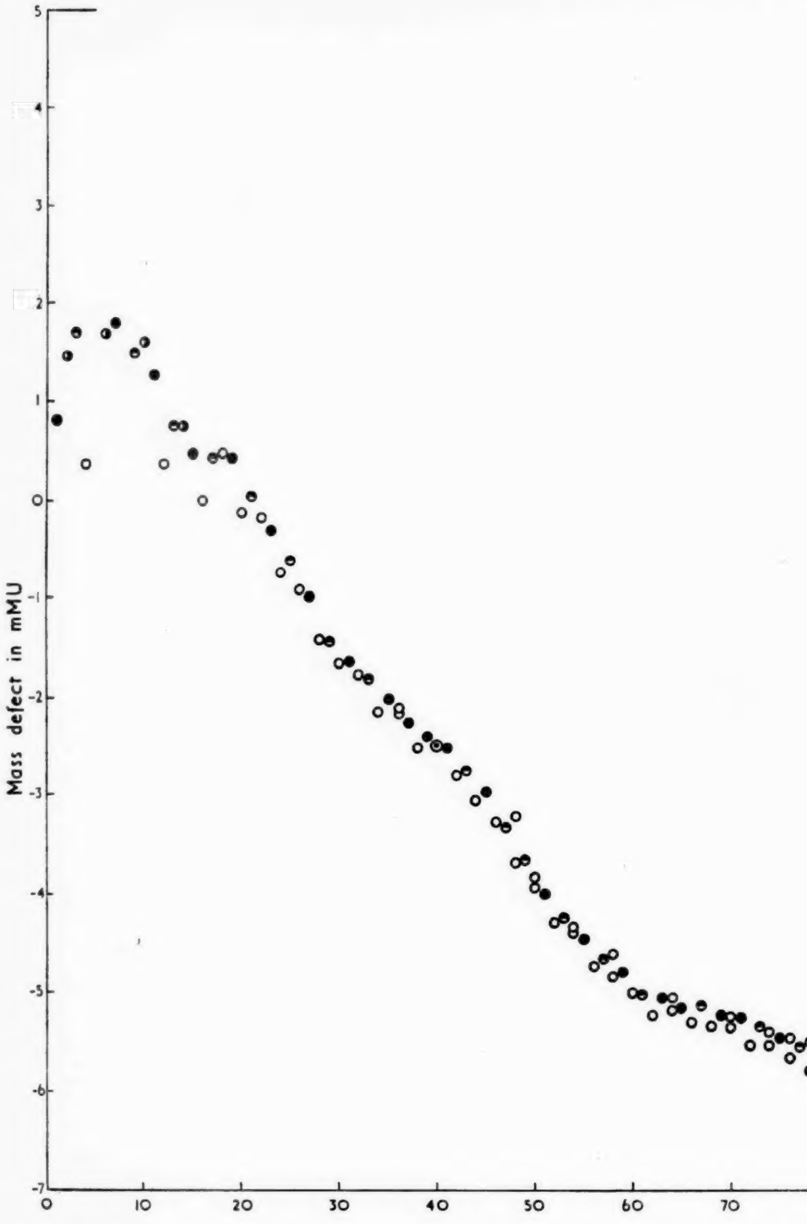
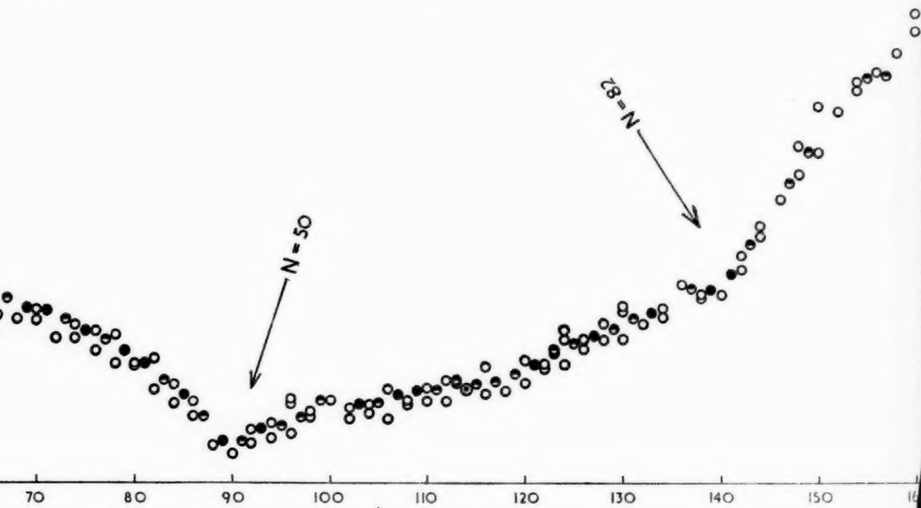
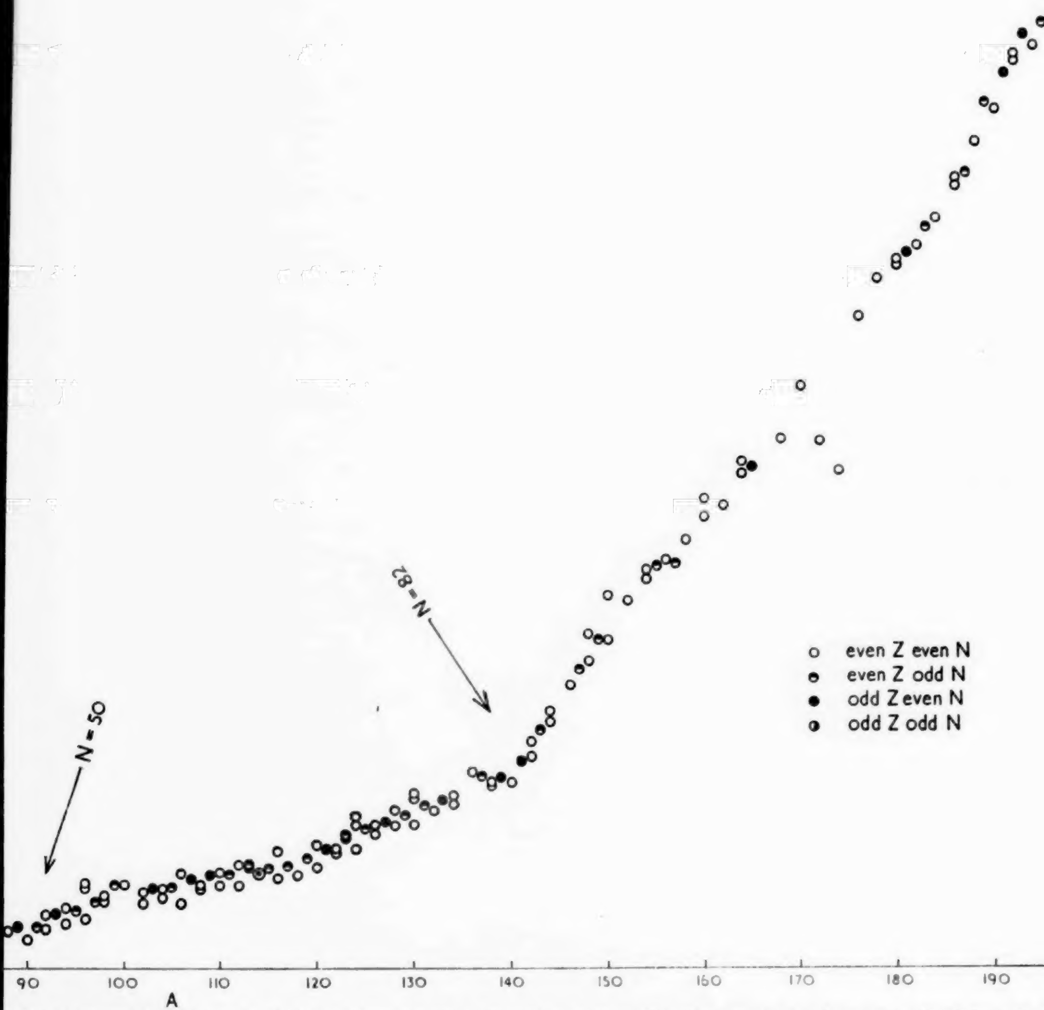


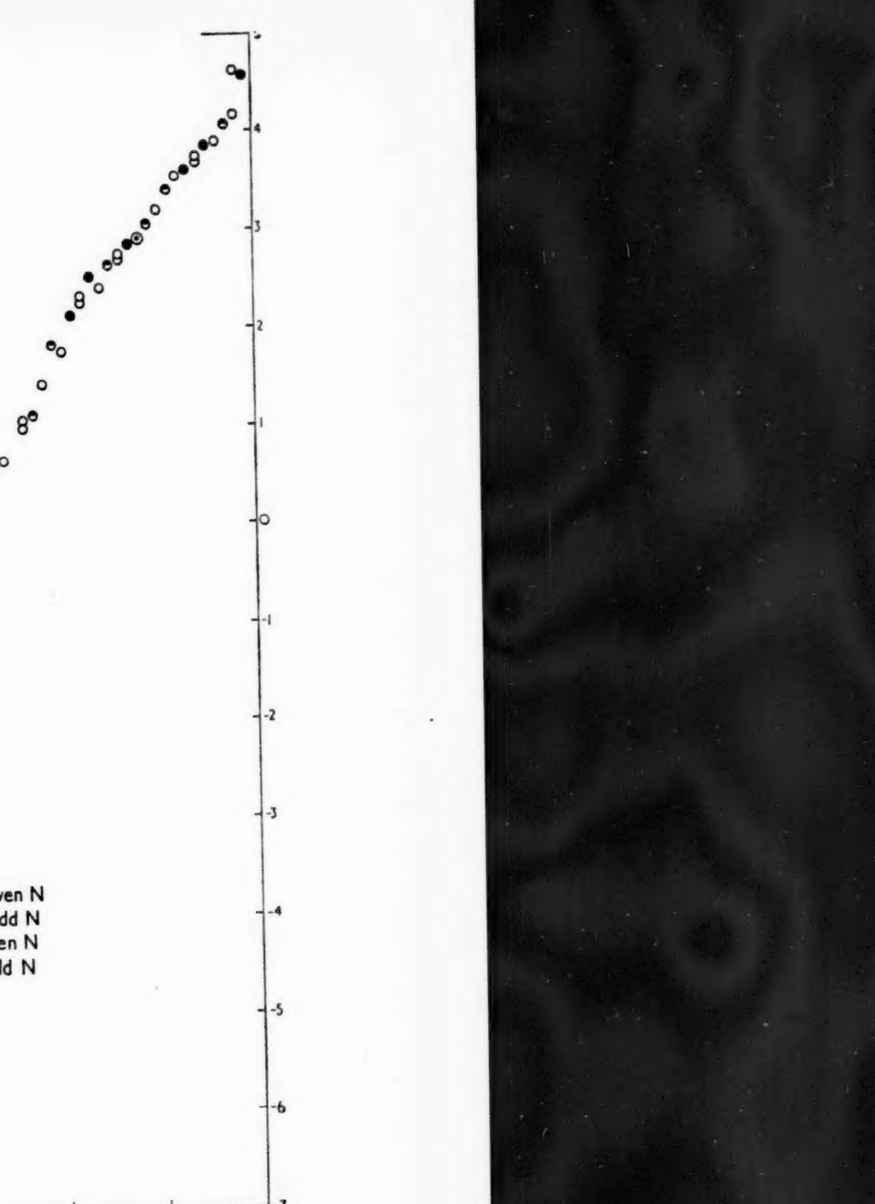
FIG. 1. Variation of mass defect with A; all isotope species. The abscissal scales of fig



l scales of figures 1 and 2 should be multiplied by 10^4 and those of figures 3 and 4, by 10^3, to give mMU; the



2 should be multiplied by 10⁴ and those of figures 3 and 4, by 10³, to give mMU; the negative sign has been omitted from figu



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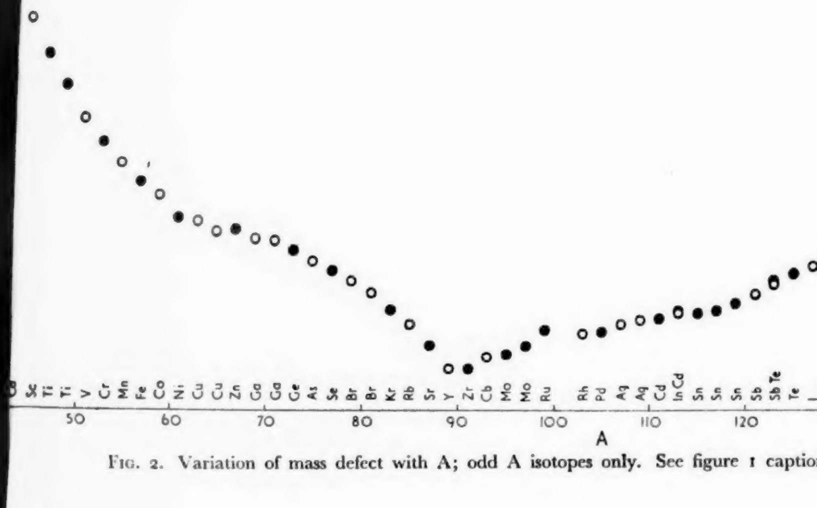
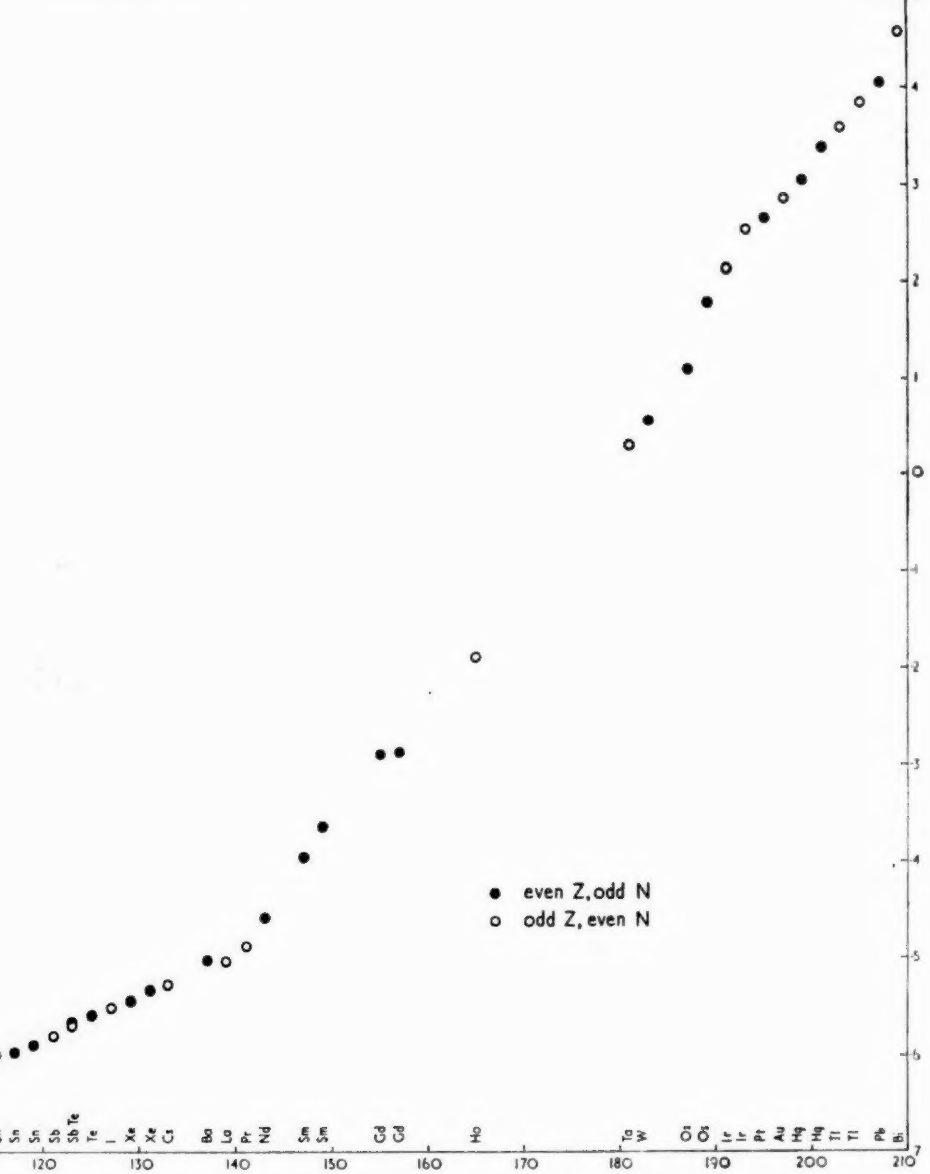


FIG. 2. Variation of mass defect with A; odd A isotopes only. See figure 1 captio



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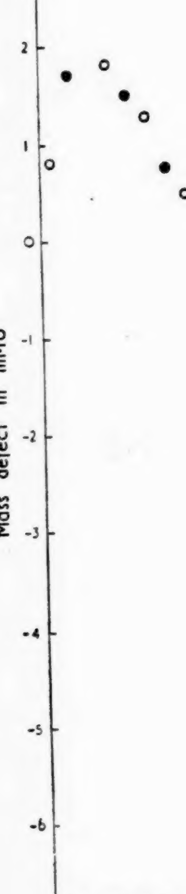
Mass defect in mMU
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
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10
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He
Li
Be
B
C

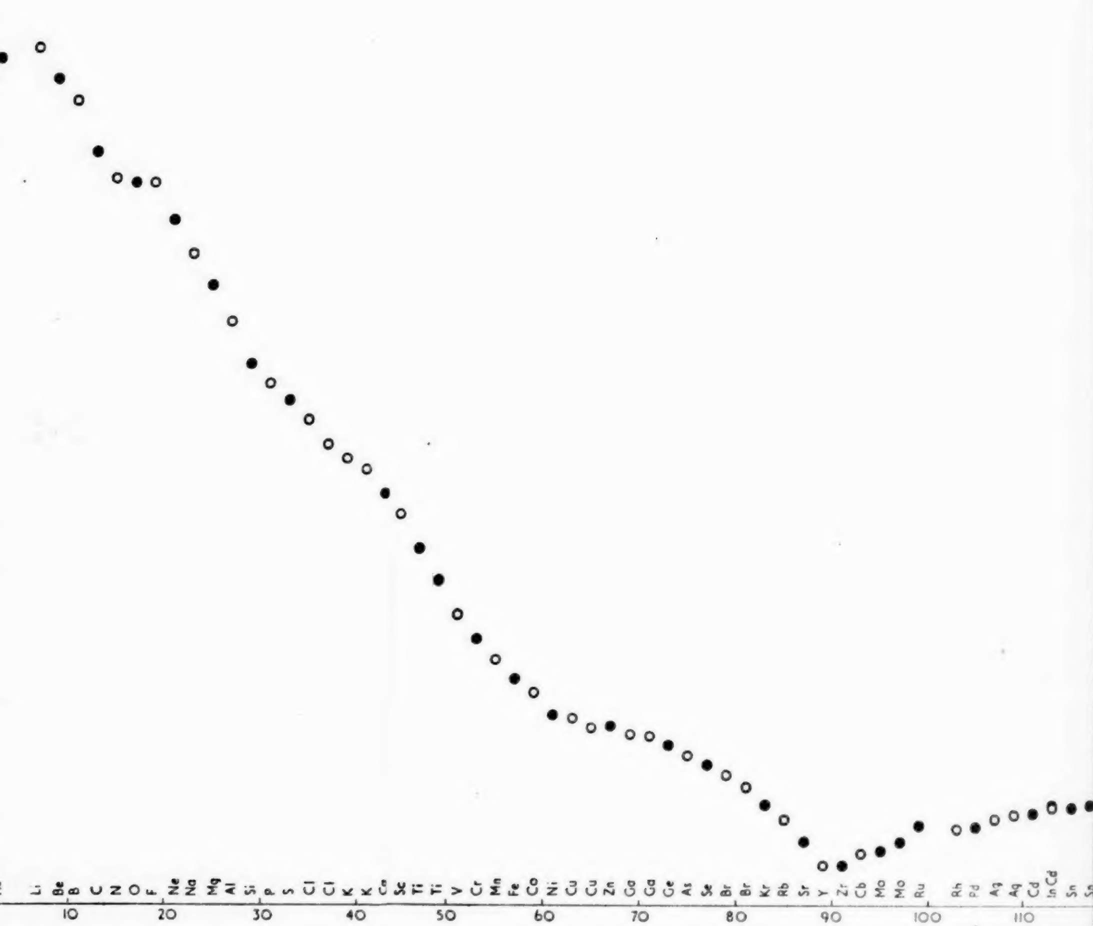

FIG. 2. Variation of mass defect with A; odd A isotopes only. See figu

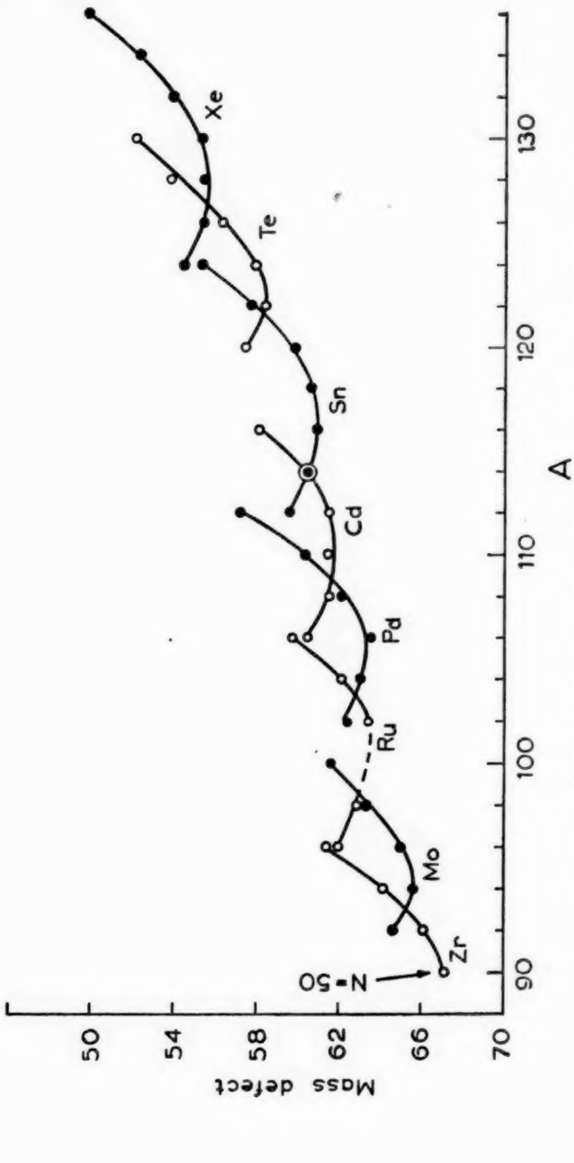

FIG. 3. Mass defect distributions for given values of Z over the range Z = 40 (Zr) to Z = 54 (Xe). Even A isotopes only. See figure 1 caption for notes on abscissal scales.

species seem to participate in the development (fig. 5) involving isotope abundance distribution and variation (Ahrens, 1957).

Acknowledgement

The Society desires to acknowledge the receipt of a grant from the University of Cape Town toward the cost of publication of this paper.

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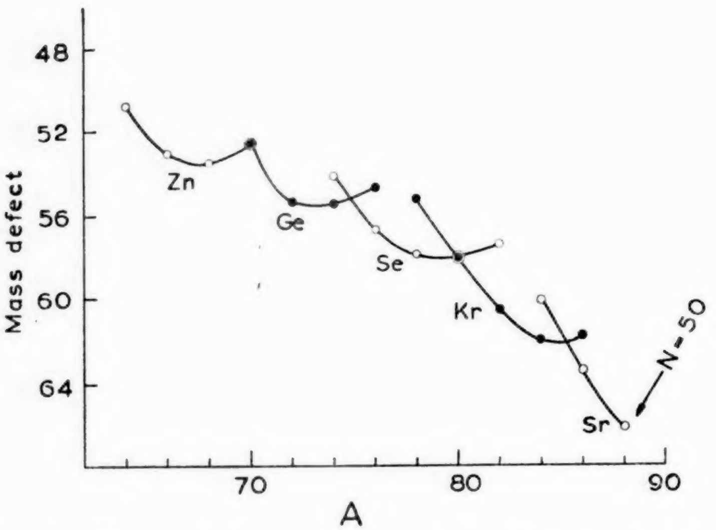

Fig. 4. Mass defect distribution for given values of Z over the range Z = 28 (Ni) to Z = 38 (Sr). See figure 1 caption for notes on abscissal scales.

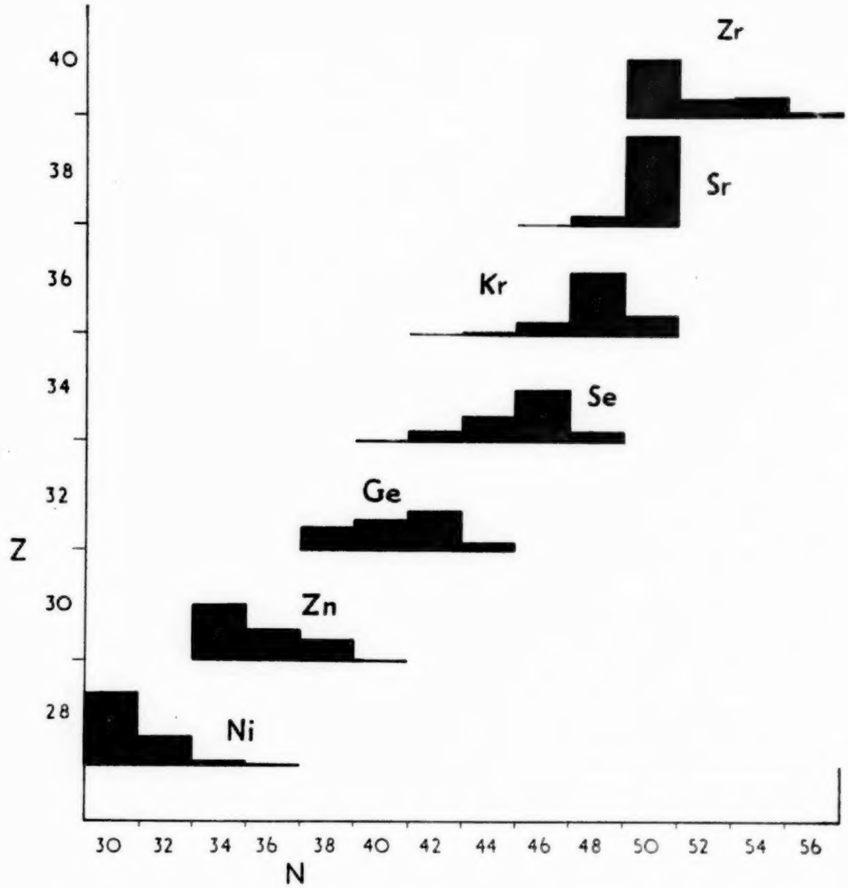

FIG. 5. Isotope abundance distribution and variation between Ni^{58} (Z = 28 and N = 30) and Z = 40. (After, Ahrens, 1957.)

AN INCLUSION-BEARING OLIVINE MELILITITE FROM MUKOROB, SOUTH WEST AFRICA

By J. J. Frankel
Department of Geology, University of Natal, Durban

(With Plates VIII to IX and one text-figure)

(Read September 19, 1956)

A thin porphyritic dyke, cream-brown in colour, is intruded into Upper Dwyka shales near the kimberlite pipe on Mukorob, South West Africa. Now highly calcitized, the rock was probably an olivine melilitite when fresh. Black ellipsoidal ilmenite-covered altered olivine inclusions give the rock its curious appearance. Other inclusions of rounded replaced olivine and rock types commonly found as cognate xenoliths in kimberlite are scattered throughout the dyke rock.

Although the rock is intensely calcitized, it has been possible from the investigation to offer some suggestions concerning the close petrogenetic association of kimberlite and olivine melilitite.

Introduction

Kimberlite pipes and associated dykes have long been known from the area between Mount Brukkaros and Gibeon in South West Africa (Scheibe, 1906; Range, 1912). The pipes and dykes are often covered by surface limestone and the highly weathered surface zone of these intrusives has been replaced by calcite (Wagner, 1914, 100).

There are many calcitized dykes in the kimberlite area between Mount Brukkaros and Mukorob (also spelt Mukerop, Mukorub). They are considered to be either kimberlite or olivine melilitite and frequently contain numerous inclusions, especially garnet (personal communication, Dr. H. Martin).

One of these dykes, on the farm Mukorob, holds nodule-like inclusions which give the rock an extraordinary appearance. Mr. E. Zelle, Curator of the South West African Museum in Windhoek, collected a number of specimens of this rock and at the suggestion of Mr. K. Schneider of Simplon, Keetmanshoop, kindly gave them to me for examination.

According to Dr. Martin, the outcrops are extremely poor, but the rock seems to occur as a thin fissure cutting through Upper Dwyka shales. It is about one foot wide, has as easterly dip and the inclusion-rich portion can be followed for about 200 yards along the strike. The dyke is close to the Mukorob kimberlite pipe but, unfortunately, the exact relationships in the field are not quite clear.

Macroscopic Appearance

In hand specimen the dyke rock on both fresh and weathered surfaces is dull cream-brown in colour. Weathered surfaces are rough and pitted, with solution

furrows so characteristic of carbonate rocks. There are also small cavities up to $1 \times 0{\cdot}5$ cm. across, lined with calcite crystals.

The rock is made up of a fine-grained groundmass peppered with brighter yellow-brown subrounded grains and minute speaks of black iron ore. Black, shiny ellipsoidal inclusions, either whole or broken, give the rock its curious appearance (Plate VIIIA). These inclusions are composed of a core of pale brown or creamy material surrounded by either a single shell or, more frequently, two concentric shells of a black metallic mineral identified as ilmenite.

There is, in addition, a large number of inclusions composed of other minerals or rock fragments. These are rough or irregular on exposed surfaces of the rock, but across fractured or sliced surfaces they are similar in cross-section to the ilmenite-covered inclusions. Serpentinized and silicified olivine, fragments of ilmenite, garnet, green amphibole, green and altered brown varieties of pyroxene, eclogite, pyroxenite, and garnet-ilmenite rock are easily recognized.

Dilute hydrochloric acid dissolved 80·5 per cent of a sample of the crushed rock, carefully freed of inclusions. The insoluble residue was composed of 56 per cent of fine, highly magnetic iron oxide and the rest was essentially secondary quartz with some inclusion fragments. Another sample substantially freed of inclusions, and then finely pulverized, contained 32·9 per cent carbon dioxide, which is the amount present in 75.8 per cent calcium carbonate. Qualitative tests showed that the dissolved material was very low in iron and alumina and slightly more than traces of magnesium was found.

Petrography of the Dyke Rock

Examination of thin sections has shown that except for iron-ore cubes, all the original minerals of the rock have been replaced by calcite. Identification of several minerals is possible from crystal outlines which are still visible in thin section, and thus the probable original composition of the rock can be determined.

The rock exhibits a typical porphyritic texture characteristic of basic or ultra-basic lavas or thin hypabyssal intrusion (fig. 1 and Plate VIIIB). In plane-polarized light, translucent, yellow-brown phenocrysts of euhedral to subhedral replaced olivine are set in a mesostasis of similar colour.* Small equant opaque grains of iron ore or chromite of early crystallization lie within the olivine and thin dark borders of alteration magnetite surround many of the olivine phenocrysts.

A large number of colourless phenocrysts are now composed of clear calcite. Each crystal extinguishes uniformly between crossed nicols. There are reasonably clear size and shape differences between small stumpy and thin laths, and larger crystals lying either singly or in partial stellate arrangement. The outlines of some of the larger crystals resemble basal sections of pyroxene and are similar to the pyroxene in certain nepheline basalts from the Eifel. Frequently only calcite cleavages are seen in the colourless crystals, but a thin cleavage line in the smaller crystals and inclusions down the middle of larger laths—features so typical of

* For details of grain-size measurements see Table 1.

melilite—may be observed. These laths are considered, therefore, to have been melilite. They are larger than the melilite crystals in many South African olivine melilitites, but they resemble crystals in the Namaqualand occurrences, and more particularly, those in a melilite basalt from Swabia.

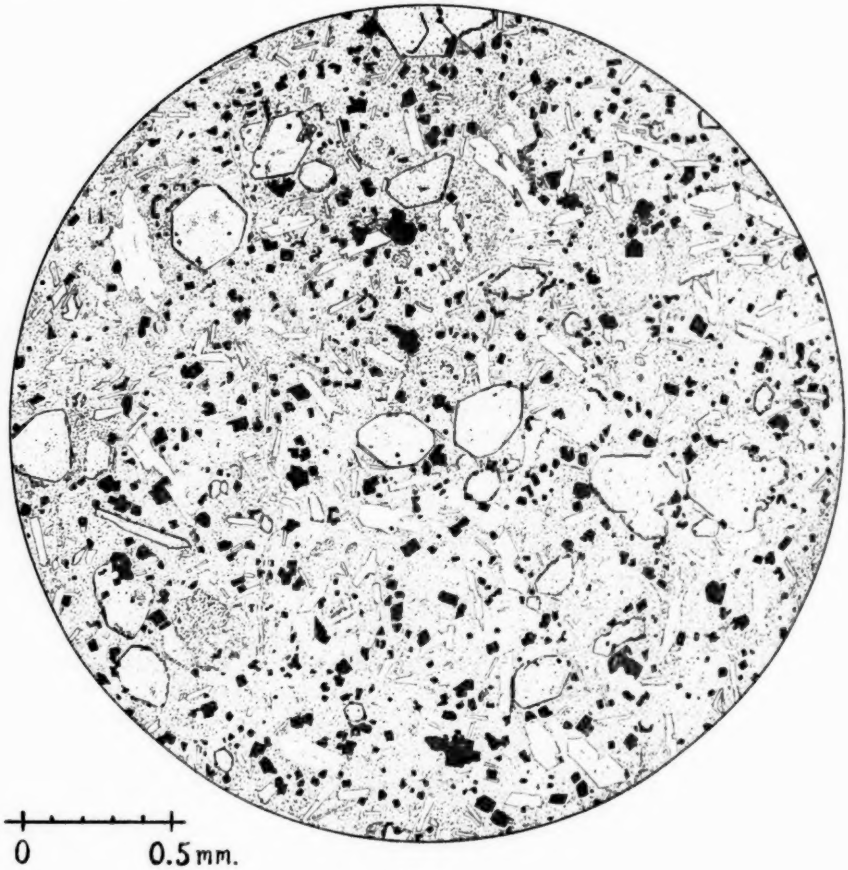

FIG. 1

Camera Lucida drawing of thin section of Dyke Rock

Small, equant crystals of strongly magnetic iron ore are scattered throughout the groundmass. In polished section the grains are rather like ilmenite in colour, but are isotropic. They are only slightly darkened by 1 : 1 hydrochloric acid, and are harder than magnetite, but softer than ilmenite. Separated grains contain 13·9 per cent titanium dioxide. The mineral is, therefore, titano-magnetite.

Faint parallel and radiating structures in the mesostasis may have been phlogopite and zeolite; there are small, dark grey-brown granules, originally perovskite, and diffuse yellow-brown streaks probably of iron-stained leucoxene.

Scheibe stated that the Mukorob kimberlite is particularly rich in apatite. No crystals of this mineral were recognized in section, nor could it be detected in heavy mineral crops. Because of the deceptive resemblance of apatite to melilite (Wagner, 1914, 71), it is possible that some of the smaller clear laths may have been apatite, although no basal hexagonal sections were seen. Original apatite, like most of the other minerals, must have been replaced by calcite and the phosphate content redistributed throughout the groundmass which contains 1·59 per cent P_2O_5. This amount, although of the correct order for such rocks, does not indicate whether there has been migration of phosphorus.

No cancrinite or nepheline was recognized among the minerals in the specific gravity range 2·5 to 2·7, recovered by centrifuge treatment. It is impossible to determine whether any nepheline was originally present in the rock. Much of the mesostasis may have been a glassy base.

The texture and grain sizes show little variation, but the distribution of the minerals does vary considerably. For example, there is often a high concentration of iron-ore cubes against inclusions.

Micrometric analyses of the matrix could only be carried out over rather small areas because of the closeness of inclusions. An average of the results obtained from several fields gave (volume per cent):

Olivine (all altered) 11·4; Iron ore 15·6, Clear areas 20·0, Unresolved 53·0.

A careful Rosiwal measurement over the Camera Lucida drawing (fig. 1) by one of my students, Mr. R. R. Maud, gave:

Olivine (all altered) 9·8, Iron ore 11·0; Clear areas 12·8; Unresolved 66·4.

The differences between the results serve to emphasize the variations in the mineral distribution.

From a comparison with nepheline basalts and olivine melilitites from the Namaqualand area in particular, it is concluded that this rock was originally an olivine melilitite.

Petrography of the Inclusions

The inclusions account for 35 to 40 per cent of the rock in which they lie without any definite orientation (Plate VIIIa). In some specimens there are so many inclusions that there is only about 25 per cent of rock 'matrix' (Plate VIIIc).

Rounded and ellipsoidal bodies which were originally olivine crystals are the dominant type of inclusion.* Under the microscope they are colourless, have characteristic fractures and are quite distinct from the smaller, translucent, brown altered olivine phenocrysts of the dyke rock itself. Crossed nicol examination shows that the original olivine was replaced by serpentine, in turn replaced by quartz. Thin chrysotile veinlets lie in the replaced serpentine and high power shows that the later quartz is made up of minute hexagonal prisms. Late calcitization has pene-

* For details of inclusion dimensions see Table 2.

trated the crystals along fractures; such portions are now deep brown and almost opaque.

Zones of a deep brown alteration mineral, probably original reaction enstatite, encircle most of the olivine. Few crystals are bordered by magnetite granules so common even to slightly ferriferous altered olivine.

The most striking inclusions are those covered by a shell of ilmenite. The central parts of the inclusions are either brown in colour, almost opaque and calcitic, or clear quartz (Plate VIIID). There is no real difference in appearance between the cores of these rounded olivine crystals and those which are not covered by ilmenite.

There may be one, more commonly two, or in some instances three concentric ilmenite shells, each up to 1·5 mm. thick. The inner shells have smooth inner and outer surfaces. The outer shell, usually smooth or finely pitted on the outside, shows progressive replacement of the olivine core (Plate IXA).

A study of polished sections reveals that the shells are made up of ilmenite grains which average 0·3 mm. in diameter; the grains are rarely twinned; the texture is equigranular (Plate IXB). All the characteristic properties of ilmenite such as colour, reflectivity, strong anisotropism and reaction to etching reagents, were observed.

A number of the ilmenite-covered inclusions were finely ground and repeatedly treated with dilute hydrochloric acid. After water-washing, the ilmenite powder was dried and separated from other minerals by centrifuging in methylene iodide. A chemical analysis gave the following results:

	(1)	(2)	(3)
SiO_2	0·6	—	2·00
TiO_2	50·30	49·27	50·00
Fe_2O_3	10·77	11·27	10·80
Cr_2O_3	2·16	0·70	—
FeO	25·11	29·34	28·80
MnO	0·21	0·29	—
MgO	10·35	8·87	9·00
CaO	0·13	0·13	—
	99·63	99·80	100·60
S.G.	4·376	4·556	4·42

(1) Ilmenite shells around olivine inclusions in olivine melilitite, Mukorob, South West Africa. Analyst. J. J. Frankel. Titania determined by G. M. Hamilton.

(2) Ilmenite, Mukorob, South West Africa. (Wagner, 1914, 61.)

(3) Ilmenite inclusion, Monastery Mine. (Williams, 1932, 2, 384.)

The ilmenite is magnesian and contains about 31 per cent of normative geikielite ($MgTiO_3$). In this respect it is similar to ilmenite from kimberlite pipes at Mukorob and elsewhere in southern Africa. Apart from a peculiar eutectic association

described by Williams (2, 384), all the ilmenite in kimberlite occurs in diopside-ilmenite rock, associated with garnet, or scattered as solid fragments ranging from minute grains to inclusions several centimetres in cross-section. Shells or crusts of ilmenite have not been recorded from Southern African kimberlites.

The presence of actual kimberlite inclusions could not be established conclusively, owing to the intense calcitization of suspect rock fragments. In a slide kindly made in Professor Tilley's laboratory at Cambridge, a large fragment of an ilmenite-rimmed altered olivine and the greater portion of a composite inclusion are seen (Plate IXc). Within this inclusion are fragments of eclogite composed of a green pyroxene ($2V\gamma 62°$) and a pink garnet ($n = 1{\cdot}743$); grains of altered olivine and thin plates of a phlogopite, all lying in a dense, brown, almost structureless material which has a clear-cut margin against the dyke rock. It is possible that this is an actual kimberlite inclusion which holds a cognate xenolith. Similar, but smaller inclusions were seen in other slides.

Inclusions of ilmenite-garnet and ilmenite-pyroxene rocks, phlogopite-glimmerite, altered norite with fresh feldspar (An_{62}), quartz granulite and one of arkose were noted in thin section. There are inclusions of foxy-red altered olivine crystals, and of peridotite in which olivine is associated with similarly coloured, striated crystals of enstatite-bronzite. No optical determinations were possible on these highly altered minerals.

There are fragments of unaltered xenocrysts such as prismatic green hornblende (α 1·640,* γ 1·657, Z ^ c 17-19°), two varieties of enstatite, (γ 1·671 and α 1·666, γ 1·675), brighter blue-green chrome diopside (or rather, jadeite diopside), (α 1·676, γ 1·706, 2V γ 62°, Z ^ c 41°), with two varieties of garnet; pale pink (n 1·743) and darker pink (n 1·749). Ilmenite occurs as small, solid grains, and a few rounded or elongate zircon and rutile crystals in the range 0·06 to 0·2 mm. diameter, were recovered by heavy mineral separation.

Petrological Relationships of the Dyke Rock

Near surface, both the Mukorob pipe and the dyke rock have the same yellow-brown colour and are highly calcitized. Calcitization was a relatively recent process, probably part of the cycle of surface limestone formation.

The Mukorob pipe holds many fragments of dolerite (Karroo age?), sandstone and, more particularly, dark grey shale (probably Dwyka), in addition to cognate xenoliths. The dyke specimens available contain hardly any accidental inclusions. Except for the ilmenite-encased olivine, the assortment of inclusions in the dyke rock is similar to that of cognate xenoliths in the Mukorob and other kimberlite occurrences in Southern Africa. In fact, the optical properties of xenocrysts in the dyke are practically the same as those recorded for like material in kimberlite (Wagner, 1914, 64; Partridge, 1935, 201 and 208).

The inclusions in the dyke exhibit a high degree of both sphericity and rounding, probably higher than in those of kimberlite. The size range may also be more limited, as there were no very large inclusions in the specimens examined.

* Refractive index determinations in Na light, all ± ·001.

The dyke may cut through the Mukorob pipe with which it is almost in contact at surface, so that a source of inclusions is at hand. However, there seems no reason why the magma should have taken up so many cognate inclusions and some kimberlite, during its passage through the pipe. Calcitization has made petrographic determination difficult, but few composite inclusions have attached fragments of possible kimberlite. In any event, movement within the dyke magma would cause softer, attached fragments to be removed from the harder xenoliths.

Such an abundance of cognate xenoliths, points rather to their presence in the olivine melilitite magma at depth, before injection to higher levels. This implies that the kimberlite and olivine melilitite magmas were in similar or allied environments in depth.

The close field relationship of the two rock types in many areas has always suggested a close genetic connection. Taljaard (1937) outlined conditions under which kimberlite and olivine melilitite (olivine basalt) could have come from a common magma. Kimberlite was thought to be hydrothermally altered by hot fluids from the parent magma reservoir, whereas olivine melilitite escaped such hydrothermal alteration. Holmes (1937, 391) has pointed out that while the temperature of mobile parts of kimberlite pipes was so low that accidental inclusions of coal and fossil wood have not been affected, olivine melilitite magma, on the other hand, is a potent agent in metamorphism and transfusion of materials like granite and quartz. The relationship is, therefore, not really a simple one.

Ilmenite-encased olivine xenoliths have not been recorded from any kimberlite pipe or dyke in Southern Africa. They are the feature which distinguishes two otherwise similar cognate xenolith assemblages.

It is suggested that this inclusion-bearing olivine melilitite represents a portion of the 'magma of ultra-basic character' which gave rise to kimberlite. Retained in depth until well after the main body of the magma with xenoliths and volatiles was injected into higher levels, it was itself very likely modified by invading and transfusing emanations. During this period, late magmatic ilmenite crystallized round and within many of the rounded olivine or peridotite inclusions held in the magma. The texture of the ilmenite is typical of magmatic, high-temperature conditions. Oscillation in the level at which the magma was retained, might account for eclogite or 'amphibolite' inclusions picked up later, not having ilmenite shells.

Movement in the magma that may have solidified partially from time to time, was responsible for the fracturing and breaking up of many of the ilmenite-olivine xenoliths.

The dyke is thus a late injection of typical olivine melilitite holding cognate xenoliths which probably came up from depth in the magma, and were not picked up during passage through a kimberlite body.

This rock may well be a missing link in the kimberlite-olivine melilitite association. Perhaps we would get a little nearer to the answer if the rock were fresh. Only a very deep excavation or borehole might afford the necessary evidence.

Acknowledgements

I thank Mr. E. Zelle for the specimens and Mr. K. Schneider for suggesting the examination; Dr. H. Martin for field information; Dr. Morna Mathias for assistance and helpful discussion; Professor C. E. Tilley for enabling me to examine slides in the Harker Collection; Dr. S. O. Agrell for specimens of European melilite basalts, and the Director of the Union Geological Survey for the loan of thin sections.

The Society desires to acknowledge receipt of a grant from the University of Natal towards the cost of publication of this paper.

Table 1

Grain Sizes of Constituents of Olivine Melilitite in Thin Section			
Mineral	*Maximum*	*Minimum*	*Average (in mms.)*
Olivine	0·49 × 0·24	0·08 × 0·04	0·24 × 0·16
Magnetite	0·08^2	0·02^2	0·04^2
Clear laths (pyroxene ?)	0·56 × 0·32	0·2 × 0·04	0·3 × 0·16
Clear laths (melilite ?)	0·16 × 0·04	0·05 × 0·008	0·12 × 0·02
Inclusions in Olivine			0·01^2

Table 2

Sizes of Inclusions in Hand Specimen			
Inclusion	*Maximum*	*Minimum*	*Average (in cms.)*
Olivine	1·4 × 0·8 × 0·8	0·2 × 0·2 × 0·2	0·7 × 0·6 × 0·6
Olivine (ilmenite rimmed)	1·8 × 1·5 × 1·0	0·8 × 0·6 × 0·6	1·0 × 1·0 × 0·8
Enstatite-peridotite			1·0 × 0·8
Eclogite			0·4 × 0·4
Ilmenite-garnet			1·0 × 1·0
Ilmenite			0·3 × 0·2
Pyroxene, various / Hornblende			0·7 × 0·4
Garnet			0·6 × 0·6

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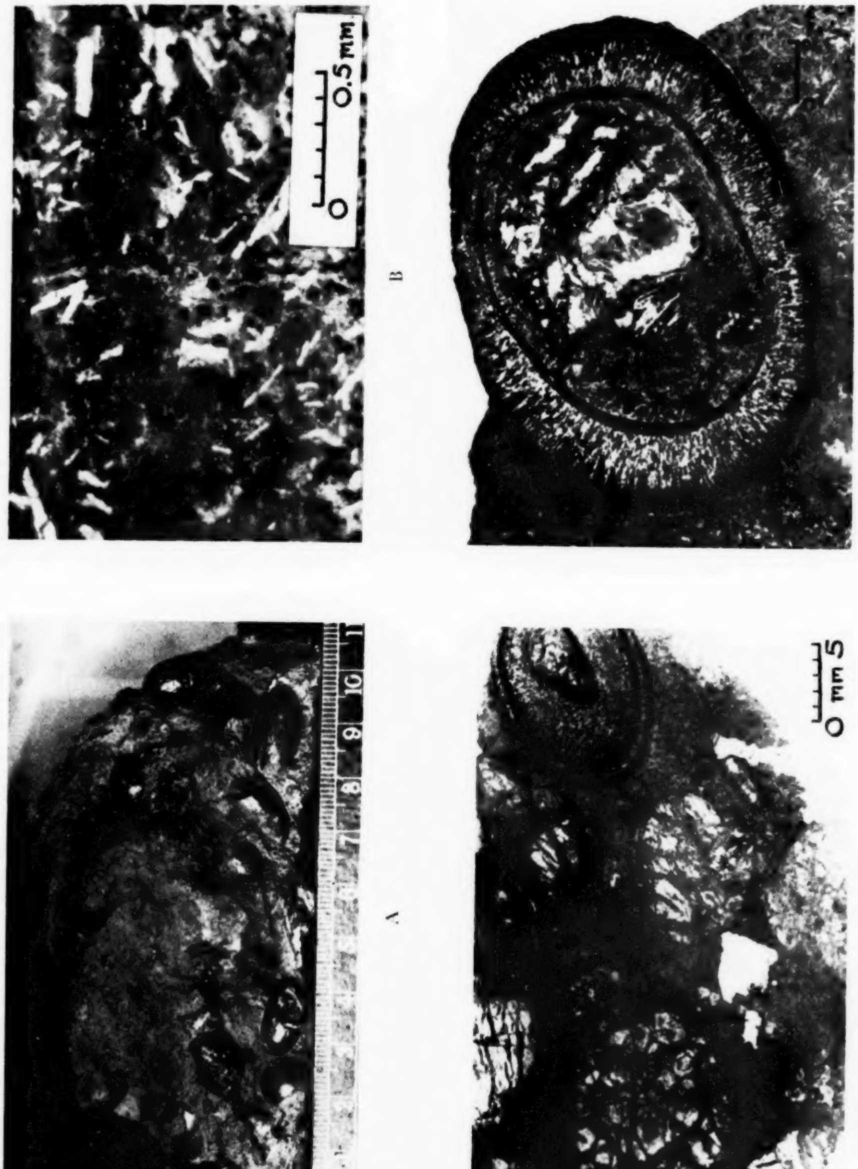


A

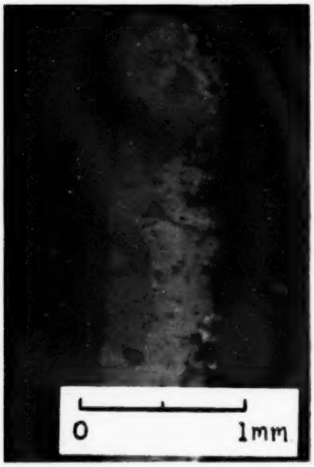
B

C

D

A. Hand specimen of inclusion-bearing dyke rock, Mukorob. B. Thin section of the dyke rock. Plane polarized light. C. Tightly packed inclusions with little of the dyke rock between them. Plane polarized light. D. Ellipsoidal ilmenite-covered xenolith of serpentinized olivine crystals. Note the radial development of ilmenite towards the centre in which, although now composed of quartz, the serpentine structure is preserved. Plane polarized light.

A



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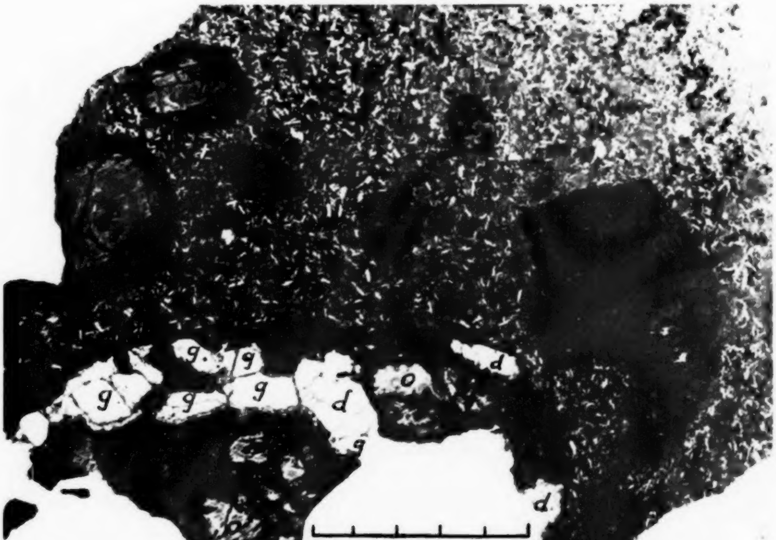

C

A. Outer and inner shells of ilmenite around an olivine inclusion. Replacement growth developed from the outer shell towards the centre of the inclusion. Plane polarized reflected light. B. An inner ilmenite shell around an olivine inclusion. Note the equigranular texture and the characteristic strong anisotropism. Reflected light, nicols slightly uncrossed. C. Olivine melilitite containing olivine xenocrysts rimmed by iron-rich alteration material, a broken ilmenite-covered inclusion, and a composite inclusion containing eclogite fragments, scattered olivine grains and phlogopite flakes. d = chrome diopside, g = garnet, o = olivine. Plane polarized light.